QUALITY CONTROL
FOR
AUTOMATIC INSPECTION OF THREADED COMPONENTS

BY

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IN THE NAME OF

ALLAH

THE MOST COMPASSIONATE

AND MERCIFUL

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DECLARATION

I declare that all the work described in this thesis is entirely the work of the author, performed whilst undertaking the research project in the period January 1990 to August 1991. This thesis has not been submitted as an exercise for degree at any other Institute or University.

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NOTATION

d : Nominal diameter of thread (mm).

S : r.p.m of work.

N : r.p.m of cutter.

n : Number of teeth in cutter.

f : Feed per revolution.

M_v : Measured value.

T_v : True value.

M_s : Maximum scale value.

Sen : Sensitivity.

C.O.S: Change of output signal.

C.I.S: Change of input signal.

y : Function.

x : Variable.

C, m : Constants.

m_1 : Motor number one.

m_2 : Motor number two.

A : The lowest limit of accuracy.

K : Relative linearity error.

K_a : True value of quantity.

K_b : Observed value.

X : Statistical mean.

σ : Standard deviation.

T_a : Developed torque

I_a : Current.

w_m : Shaft velocity.

V : Linear velocity.

w : Angular velocity.

ϕ : Flux.

T_m : The torque developed on the motor shaft.

k_a : Developed torque.

T : Torque produced by motor.

E : Voltage accrose the motor.

J : Inertia.

CL : Centre line.

LL : lower limit.

UL : Upper limit.

BS : British Standard.

SQC : Statistical quality control.

LVDT : Linear Variable Differential Transformer.

ABSTRACT

Manual inspection and testing of threaded components, specially in high volume manufacturing processes are time consuming and costly.

There are three different types of error which may occur within the tolerance zone specified by the metric thread ISO system, which are as follows:

(i) Error of the flank angle.
(ii) Error of pitch over the length of fitting.
(iii) Error of effective diameter.

Additionally, material build-up which blocks the threaded zone may also render the component to be rejected. These error may occur due to the manufacturing process itself, either by cutting or rolling, such as tool and die wear, materials defects , etc.

This thesis describe the design and development of an automatic inspection system for threaded components.

The system consists of a mechanical sensor, which is interfaced to a PC and the operational tracing cycle of the system is controlled to carry out the following operations.

(1)- Helix path inspection.
(2)- thread form inspection.

The results of the helix path and the thread form tracing are presented for the ISO metric thread: (M6), (M8), and (M16), together with the operational cycle.

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CHAPTER ONE

1 - INTRODUCTION

In the recent years there has been a significant growth in the use of tactile probes as on-line inspection system for machine tool applications.

These probes are mounted in holders, inserted into the machine tool spindle, stored in the tool drum, and handled by the automatic tool changer in the same way that cutting tool are exchanged. When mounted in the spindle, the machine tool is controlled very much like a CMM.

Sensors in the probe determine when contact has been established with the part surface. Signals from the sensor are transmitted by any of several different means to a controller, which performs the required data processing to interpret and utilize the signal.

Touch sensitive probes are sometimes referred to as in-process inspection devices. These probes are sometimes used between machining steps in the same setup.

Some of the other calculation features of machine mounted inspection probes are similar to the capability of computer-assisted CMMs.

The features include determining the centre-line of a cylindrical part or hole, part and determining the coordinates of an inside or outside corner.
One of the controversial aspect of machine-mounted inspection probes is the fact that the same machine tool which makes the part is also performing the inspection .

In practice, however, the use of these devices has proved to be effective in improving quality and saving time in expensive off-line inspection operations . [8]

This thesis is mainly concerned with the application of quality control to threaded components.
An automatic measuring system have been developed in order to inspect the external screw threads.

In chapter two we define the measurement and standards, describe the different basic metrological concepts and the classification of the measuring methods and means, provide the automatic inspection principle and methods, in addition to the reasons of using it.

And because of the strong relationship between the automatic inspection and the sensor technologies, an explanation of sensor technologies as applied to automated inspection is given.
Also in this chapter the literature survey for screw threads, which represent the different techniques, methods, attempts to develop the methods, of inspecting the screw thread.

While chapter three gives the definitions of the screw thread for the use in mechanical engineering applications then, there are a description of the different types of the screw and the various methods of manufacturing them.

Also the different errors of the screw thread, of these effective diameter, pitch, error in pitch in relation to effective diameter, error in angle in relation to effective diameter and error at crest and root of the thread.

In addition the control of accuracy of the ISO metric screw thread which includes the basic dimension, tolerance zone and class of fit, application of the class of fit, and the designation of the screw thread are presented. The last section of this chapter explains the two general methods of inspecting screw threads (gauging, measuring).

In chapter four special definition for instrumentation then describes the various principles of the design which include, the kinematic basic characteristic of measuring devices and intelligent instrumentation.

Also a full explanation is given about the design and development of our automatic measuring system which consists of two main elements (mechanical and electronic).

These are interfaced to a personal computer for controlling and processing the different input/output

signals. Therefore two signals conversion are described with their calibration and that of the linear variable differential transformer (L.V.D.T).
At the end of this chapter there is an explanation of the software development.

The measuring principle of the system is illustrated at the beginning of **chapter five,** also the operational cycles explain the consequence of the measuring process due to the profile form and helix path inspections.

While the experimental procedure describes the importance of calibration and its effects on the results. The three ISO metric screw thread M6, M8 and M16 are used. The different results are presented at this chapter, beside that, the different linear and angular velocities used for inspecting these bolts are illustrated.

Chapter six, is mainly concerned with discussing, comparing and analyzing the different results which were obtained due to the various experiments.
Finally, **chapter seven** represents the conclusion of this work, and the recommendation for further work.

CHAPTER TWO

2 - LITERATURE SURVEY

2-1 Measurement and standards.

Measurement is the most fundamental method of science. It is the process of empirical, objective, assignment of numbers to properties or events of the real world in such a way as to describe them [1]. All measurements are actually relative in sense that they are comparisons with some standard units of measurement [2]. The progress of measurement has played a large part in man's scientific advancement.

Early attempts at standardization of length measurements were based on the human body. The width of finger was termed a digit, and the cubit was the length of the forearm from the end of the elbow to the tip of the longest finger. These measurements were in use at the time of the construction of the Khufu pyramid [3], [4], [5], [6], [7].

Accurate measurements are important to physics, business and finance, agriculture, medicine and health and to many everyday activities such as and travel, sports and recreation cooking and baking, and communications and entertainment [2].

Engineering dimensional measurement involves the euclidean concepts of the straight line and plane. Linear measurements are ratios expressed in terms of some arbitrary length standard, e.g. the Imperial Standard Yard or the International Prototype Metre.

Other forms of length standards are possible, but present primary length standards are defined in terms of the wavelength of monochromatic light. The establishment of the of an absolute length standard belongs to the realm of physics rather than engineering ,[8], [9].

2-2 Basic Metrological Concepts.

Metrology is mainly concerned with:

(1)- Establishing the units of measurement, reproducing these units in the form of standards, and ensuring the uniformity of measurement.

(2)- Development methods of measurement.

(3)- Analyzing the accuracy of methods of measurement researching into the cause of measuring errors, and eliminating these.

The principle of measurement is the physical phenomenon utilized in the measurement, while the method of measurement is the way the measuring principles and measuring means are used [3].

2-3 Classification of Measuring Methods And Means.

A measuring instrument is any device that may be used to obtain a dimensional or angular measurement [10]. Measurements can be generally classified as direct and indirect ones. Direct measurement are mostly used in engineering because they are simpler to perform and give immediate results.

The methods of measurement are also classed as the composite (or cumulative) method and the element method. The composite method is the most reliable method for ensuring interchangeability and is usually effected through the use of composite " ***GO*** " gauges.

The composite method is mainly used for checking product parts [3], mass production for instance [2]. The element method for checking tools and for detecting the cause of reject in product.

Contact measurement involves the direct engagement of the instrument measuring faces with the surface of the part being measured.

Non-Contact measurement features the absence of any physical contact of the instrument with measured part.

The means of measurement used in the metalworking industries can be divided into three main groups, namely:

(1)- STANDARDS.

(2)- FIXED GAUGES.

(3)- UNIVERSAL MEASURING TOOLS and INSTRUMENTS.

Here are a number of the common measuring instruments listed according to [10], use:

(a) - Linear measurement.

1- Measuring machine

a- Mechanical.

b- Optical.

(b) - Angular measurement.

(c) - Plane surface measurement.

(d) - All-Purpose special measurement.

1. Pneumatic.
2. Electric.
3. Electronic.
4. Laser.

2-4 Automated Inspection Principles and Methods.

Automation is a technology concerned with the application of mechanical, electronic, and computer based systems to operate and control production.

Inspection and testing activities represent one of the five basic functions in manufacturing (*Processing, Assembly, Material handling and Storage, Inspection and Test, Control*) as shown in figure (2-1).

When **SQC** (statistical quality control) inspection and testing are carried out manually, the sample size is often small compared to the size of the population. The sample size may only represent 1% or fewer of the number of parts made in a *high-production* run. In principle, the only way to achieve 100% good quality is to use 100% inspection.

By this approach, theoretically, only good-quality parts

Factory operations

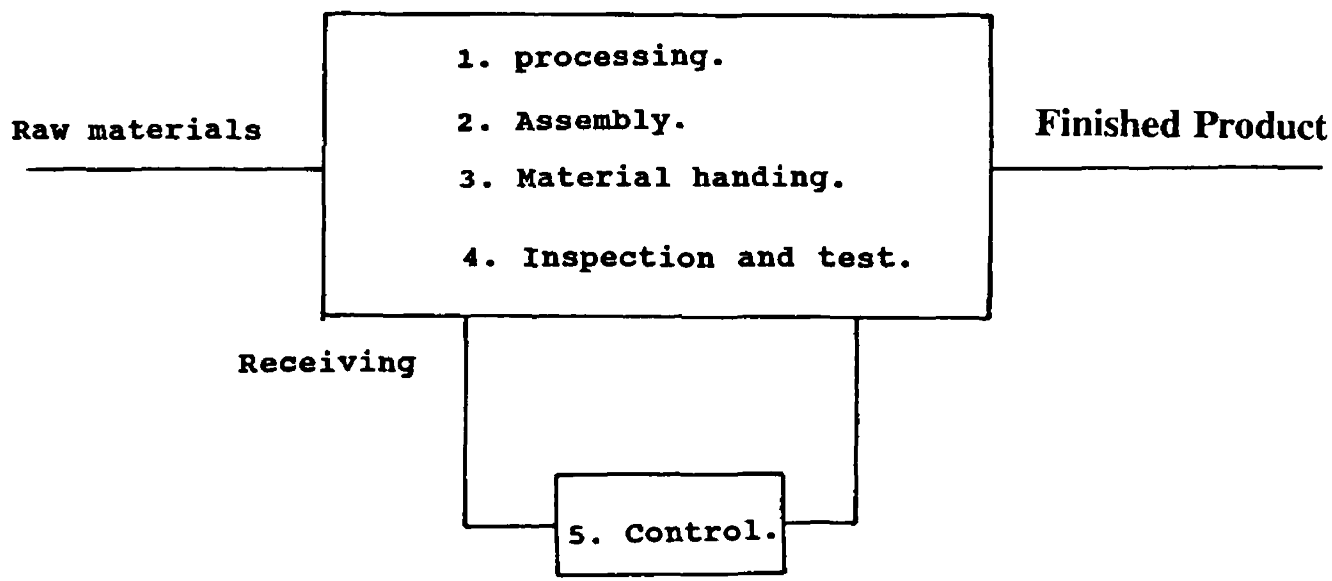


Figure (2-1)

Model of the factory showing five

function of manufacturing.

will be allowed to pass through the inspection procedure. 100% inspection using manual methods is no guarantee of 100% good quality product. Automation of the inspection process offers an opportunity to overcome the problems associated with 100% manual inspection. Automated inspection is defined as the automation of one or more of the steps involved in the inspection procedure [8].

2-5 Sensor Technologies For Automated Inspection.

The sensing element is the first element in the measurement system; it is in contact with, and draws energy from, the process or system being measured [11]. The new approaches to the quality control function are based on advanced sensor technology often combined with computer based systems to interpret the sensor signal, in addition, new software tools are being developed to automate the operation of complex sensor system and to statistically analyze the sensor measurement.

Modern automated inspection procedures are typically carried out by sensor [8]. Sensors can obtain range data, at high speed are an increasingly important part of development in the field of robotics, automated inspection and assembly [2].

A transducer is defined as a device that receive energy from one system and retransmits it, often in a different from, to another system.

On the other hand, a sensor is defined as a device that is sensitive to light, temperature, electrical impedance, or radiation level and transmits a signal to a measuring or control device [13].

There are a variety of technologies available for automated inspection [8]. A detailed survey of the types of sensors developed for this purpose is given in [14].

Contact inspection methods involves the use of a mechanical probe or other device that makes contact with the object being inspected.

The purpose of the probe is to measure or gauge the object in some way. By its nature, contact methods are usually concerned with some physical dimension of the part.

Accordingly, contact inspection methods are used predominantly in the mechanical manufacturing industries (e.g., *Machining and other Metal working, Plastic moulding, etc.)*.

Three methods of automated contact inspection that present the high end of the technology spectrum are:

(1)- *Coordinate measuring machines.*

(2)- *Flexible inspection system.*

(3)- *Inspection probes.*

Non-contact inspection methods do not involve direct contact with the product, instead, a sensor is located at a certain distance from the object to measure or gage the desired features [8].

2-6 Sensor In The Production And Quality Control.

There are two basic types of sensors. One that produces an output proportional to a change in a parameters is described as an analog device; one that produces an on/off type of output is described as a digital device [15]. Measurement in all its form is an essential part in achieving quality [10].

Sensors are currently used in a large variety of phases of production process in order to realize more systematic process control a campaigned by tighter quality control [16].

Considerable progresses have been achieved in sensor technique [17], [18], these techniques have demonstrated productivity enhancing quality control inspection automation for many type of parts [19],[20],[21].

A number of measuring and controlling tasks must be carried out automatically with appropriate sensor [22]. Non-contact distance sensors are divided into three categories depending on their mode of operation; mechanical, electromechanical, and electromagnetic [33].

Sensors for inspection or quality control must have the following features: processing speed and flexibility on one hand, and easiness of operation and reasonable price on the other hand [24].

2-7 Literature Survey For The Screw Threads Inspection.

A screw thread is a ridge of uniform section in the form of a helix on the external or internal surface of a cylinder, on in the form of a conical spiral on the external or internal surface of a frustum of a cone. They probably are the most important of all the machine elements [7].

The inspection of screw threads may be by gauging or measuring [25]. Normally they are inspected using limit gauges, but certain threads must be held to much closer tolerances, and this is particulary true of the limit gauges used for screw thread inspection. These threads must be measured, not gauged, so that they are of degree of accuracy to separate successfully the good threads from the bad when used as tools of inspection [26].

BS 919: " *Screw Gauge Limits And Tolerances* " , part 3 " *Gauges For ISO Metic Screw Threads* ", contains the recommended gauging system for checking threads of nominal diameters 1mm and larger which have been made in accordance with **BS 3643** " *ISO metric screw threads* ". Measurement of a screw thread can be very complex, there being a number of elements to be measured, some of which are interrelated [25], [9].

A screw-thread comparator-a microscope for measuring elements of an external thread appeared in 1925, it was a predecessor of the universal microscope produced in 1926. Optical dividing heads also appeared in 1925. Electrified measuring instruments of different types, such as electric switch gauge heads, indicative, capacitance and photoelectric transducers, etc have been developed since 1930s.

The introduction of these devices gave an impetus to the development of automatic gauging, thus automatic gauging machines with electric switch heads have been produced since 1937.

The main trends in further development of measuring means are: higher accuracy through better construction and the application of new physical principles; **higher inspection productivity through the use of special-purpose, mechanized and automatic gauges: and the introduction of automatic gauging control over machining operations to avoid scrap** [3].

*In a flexible production system, the duties of quality assurance can not be limited to a **GO/NO-GO** inspection of the workpiece [27],[28].*

Dimensional measurement was and always will be a vital need [10],[29], automated equipment able to perform the functions of guidance, quality assurance, measurement and process control, [29], [30].

The rising cost of quality control functions in the manufacturing sector and the increasing demands for 100% [31], [32], product inspection have stimulated the development of low cost yet powerful automatic inspection devices to augment the functions of human inspectors [31].

Sensors, together with powerful computers, form a basis for flexible automation in the fields of dimensional measurement techniques and inspection [33].

A method for measuring the surface profile [34], using different techniques can be implemented to operate under computer control [20].

Several systems have been developed for inspecting screw threads, using different techniques. A device which consisted of the non-contact type optical feeler and the automatic screw lead measuring machine with a laser interferometer, had produced [35].

Batchelor [36], introduces the screw inspection problem in term of pattern recognition. Techniques are discussed for inspection male screw threads an automatic image analysis applied to their profile for measuring:

(a)- Pitch.

(b)- Depth of thread.

(c)- Flank angle.

(d)- Radius of curvature of the crest and roots.

The ideas are all based upon well-known of visual pattern recognition techniques, the Freeman (chain) code of the profile edge is first derived and is then converted to a sequence of vectors from which a polygonal are touching the crests of the thread may be derived. Similarly an arc touching the roots can be obtained. From the crest and root arcs, another polygonal arc approximating the pitch line can be calculated.

The intersections of this arc with the profile are quite accurate indicators of the flank centres. The flank angle may then be derived by measuring the edge orientations at these intersection.

The distance between alternate intersections is an estimator of pitch. The separation of the crest and root and arc is a measure of the depth of thread. A simple optical system, resembling a shadow graph may be used to obtain a silhouette of the bolt to be inspected. The bolt can be aligned roughly using a comb-like jig and a twin-strip camera seems to offer the best resolution. Using the longest photodiode array currently available (1728 diodes) and mechanical scanning, a resolution of 2000 x 1728 might be achieved.

Batchelor has not yet had the opportunity to incorporate these ideas into an one-line inspection system, also another idea Batchelor has not yet had the chance to investigate is that of rotating the bolt during inspection.

The vision system developed by horaud [37], and charras for the screw thread inspection is constituted of figure (2-2), a vidicon camera, amplification, clamp and sampling electronic circuits, grey level and gradient detectors, direct memory access devices and a PDP-11 minicomputer system with its software facilities. The acquisition time of a 200 x 512 high resolution picture (black and white pixels or white edges on black background) is only 1/25 seconds.

The techniques developed can be used to classify the items into good or detective ones. Batchelor, also, introduces a proposals for the automatic visual inspection of female screw threads, a method relies upon a conical mirror which transforms a helix into a spiral image, the imaging system is mathematically analyzed.

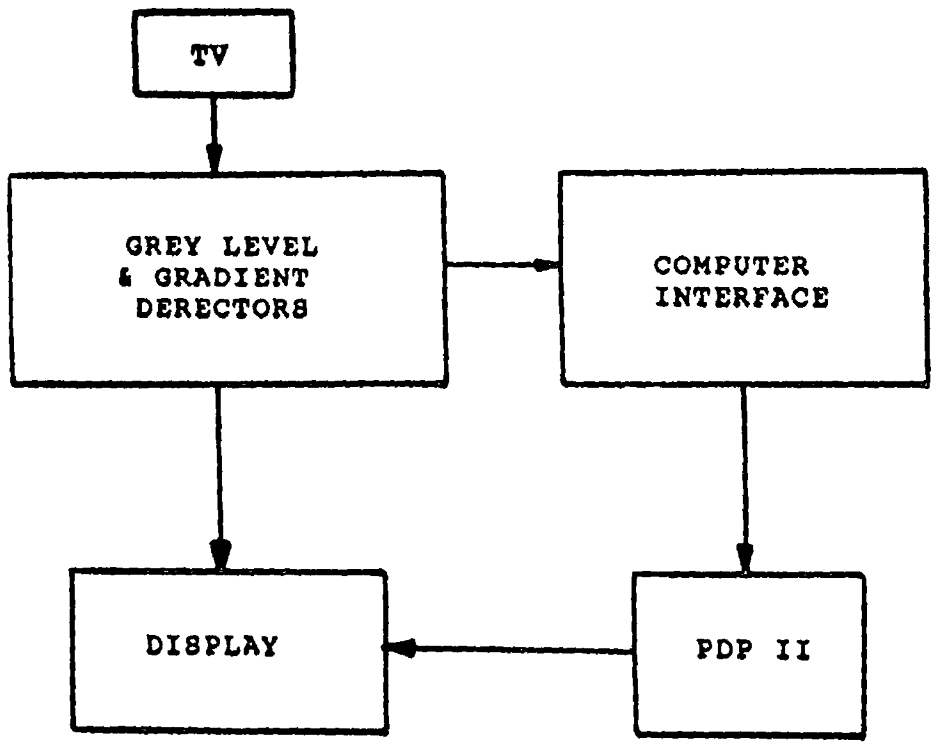

TV
GREY LEVEL
& GRADIENT
DERECTORS
COMPUTER
INTERFACE
DISPLAY
PDP II

Figure (2-2)

Techniques are used for verifying that a thread exists, checking that the thread has a given pitch, measuring the pitch, and checking for surface defects [38].

Another techniques have been developed, [39] to include the measurement of internal threads in the automatic measurement.

A programm has been developed for the CNC measuring centre, which permits the automatic testing of internal threads using a special feeler.

The measuring cycle for the measurement of threads are limited to measurement taken at the thread start and thread end , this being fully adequate for functional testing.

The feeler's starting position in this sequence of thread measurement is defined by the bore centre and the thread surface. It can be fixed by presetting the demanded value or by manual selection .

In manual positioning, the thread surface is contacted with the feeler point and the feeler point is then positioned above the bore centre.

Deviations from the bore centre are permissible, since the movement a long the coordinate axes will go on until the feeler touches the workpiece, figure (2-3).

For measurement, it is essential that the measuring points for determining the pitch diameter should be recorded in the first fully cut thread. This is done by moving from the starting position to the thread start by an amount that depends on the thread countersink and the height of the open thread flank. The first measuring

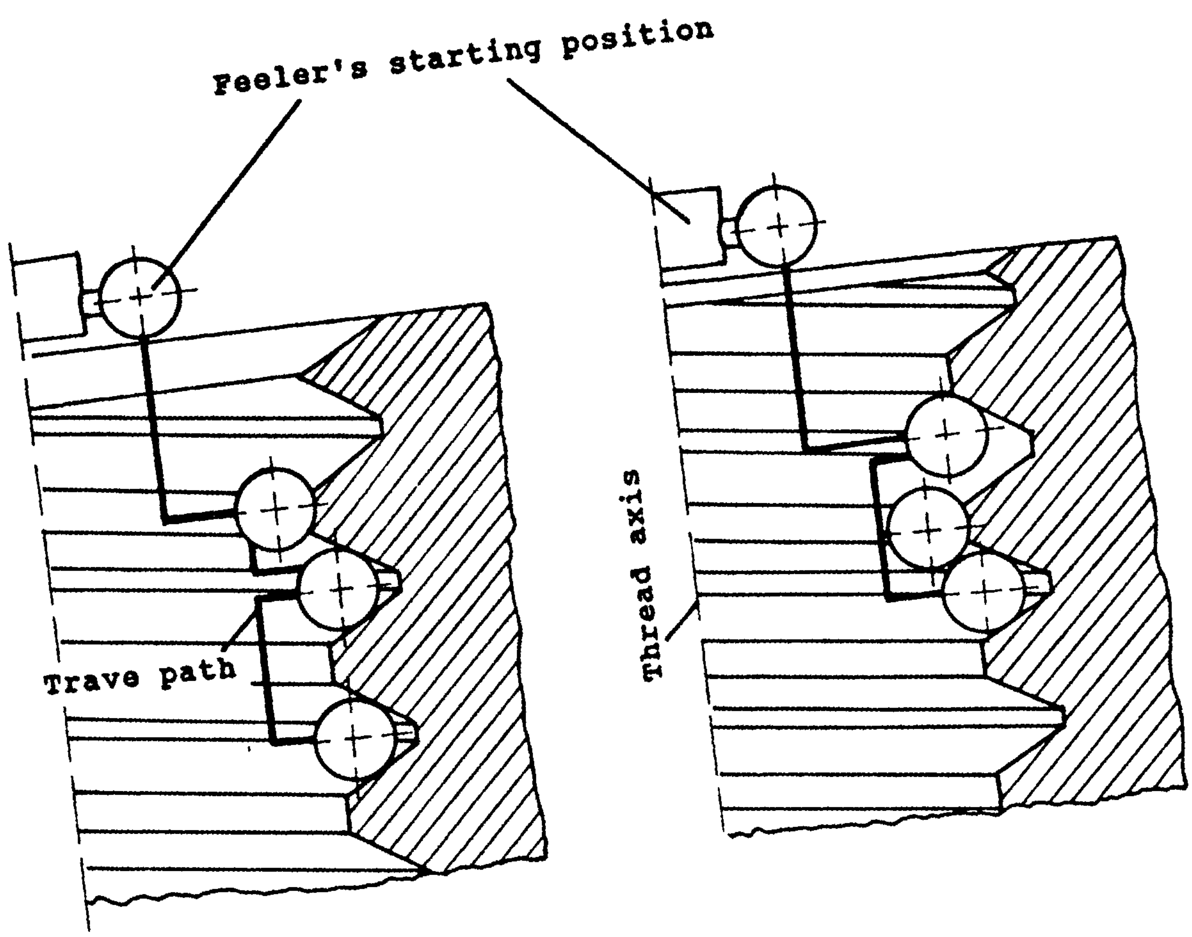


Figure (2-3)
Scanning of thread flanks
and core hole

point will then be recorded in a self-centring manner.

A flank contact test helps to make sure that the sensing ball is in contact with the thread flank and in this test, a movement is made parallel to the thread axis by an amount that is greater than the flank height in the core hole area and, in this position, a second measuring point is recorded in a self-centring manner.

The comparison of the two measuring points permits a statement to be made as to which one of the two has been determined as flank contact. After recording a third measuring point, the pitch of the thread will be obtained.

The position of the thread and the pitch diameter will be determined with the aid of further measuring points on the periphery of the first thread and through a circle calculation, followed by a correction of the sensing-ball radius.

The test of the thread depth is carried out by performing a full-flank test after movement into the given specified depth of the thread.

For this purpose, a flank contact test as the thread start will be carried out at first. The average pitch diameter and the axial location of the thread can be computed from the measuring points at the start and end by means of a cylinder calculation.

Fully- automated inspection on flexible thread inspection centre : this method of inspection is a multi-point inductive probing.

A wide variety of measured values is recorded and single parameters such as profile, taper, pitch, thread height and radius, are determined by means of the inspection electronics and the calculator. Due to a special arithmetical operation ,the total result ,the standoff , can be derived from these individual values.

Depending on the thread length, the threaded pipe section is axially divided into 2 to 4 measuring planes to spacings of 1".

Probing is carried out in radial direction. There are 6 measuring stations arranged around the thread 6^0 degree apart, see figure (2-4). The measuring head, moves along the thread. Control feature provides for switching from rapid to slow feed. Position is reached as soon as the "searcher" has found the correct thread groove. the floating overhead measuring head measuring head is orientated relative to the thread axis by 3 jaws clamping on the thread outer diameter. Once the back-off cylinder is de-energized, the measuring elements will unlock.

They are pushed forward and approach the thread by the action of spring-parallelograms ensuring constant measuring forces and, hence, preventing the measuring elements from wear.

The fact that the measuring head retracts by approx. 1 mm takes sure that the probe tips do not only probe the bottom but also the flank orientated towards the measuring head.

Upon approaching the measuring position, the inductive probes start taking measurements in 2 coordinates, i.e. radially and axially. The values measured are processed

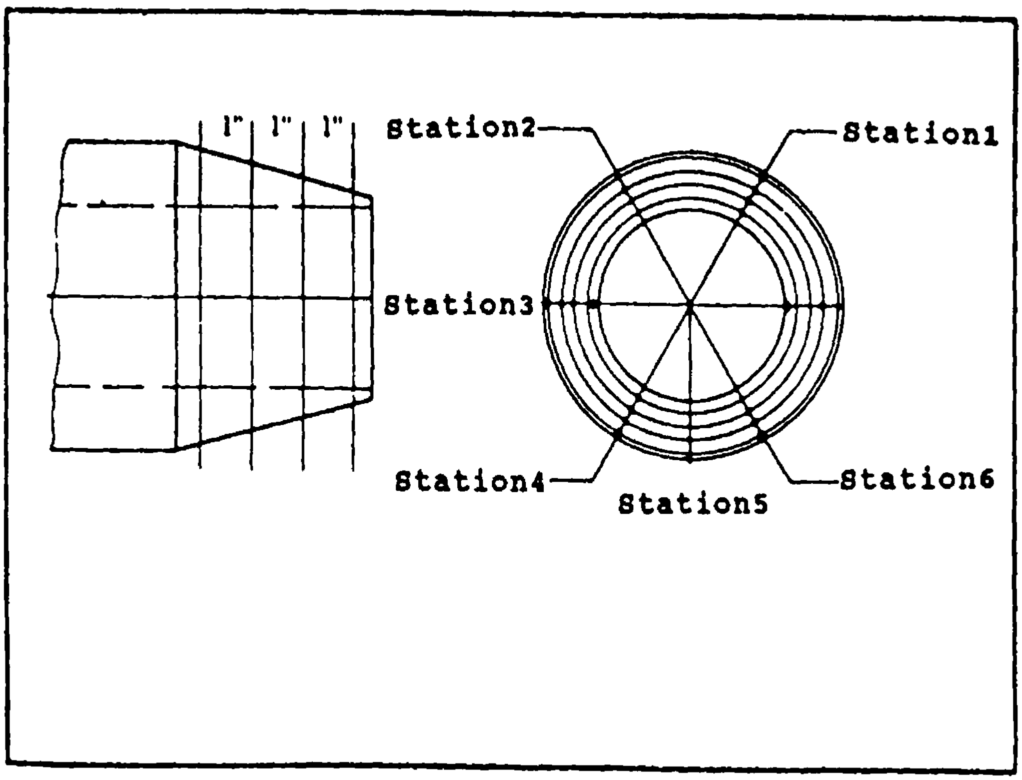


Figure (2-4)

Arrngement of measuring station

by inspection electronics, the result are made up in the calculator, displayed on a VDU and printed out indicating the pipe NO. Upon completion of the measuring cycle, a pneumatic cylinder will pull back the measuring elements to come within the collision guard.

The measuring head then returns to its initial position. The thread inspection machine, is made up of the following modules:

(1) - Basic machine with slide unit driven by servomotor.

(2)- Rotary table with holding fixture for measuring head and counterbalance.

(3)- Measuring head

(4)- Measuring head calibration station.

(5)- Electrical control with calculator and printer [40].

There exist a variety of instruments using different measurement techniques that attempt to characterize surface topography.

The majority of these techniques may be classified according to the following criteria:

- Contact or non-contact.
- 2 Dimensional (2D) or 3 dimensional (3D).
- Analogue or digital.

The contact criteria is based upon whether the measuring probe is in physical contact with the test surface during measurement.

The most popular contact probe is the use of a diamond stylus (either pyramidal or conical in shape) with a radial tip of approximately 2 micrometre.

An inherent limitation of contacting probes in the possibility of surface damage as the probe is drawn a cross the specimen. The degree to which this damage takes place is dependedt upon the geometry and loading of the stylus as well as the mechanical properties of the measurement surface [41].

CHAPTER THREE

3 - SCREW & SCREW MEASUREMENT

3-1 Definitions for use in mechanical engineering.

3.1.1 General.

(1)- Screw thread :

The ridge produced by forming, on the surface of a cylinder, a continuous helical or spiral groove of uniform section such that the distance measured parallel to the axis between two corresponding points on its contour is proportional to their relative angular displacement about the axis.

(2)- External (male) screw thread:

A thread formed on the external of a cylinder. See figure (3-1). The thread on a bolt is a typical example of an external screw thread.

(3)- Internal (female) screw thread:

A thread formed on the internal surface of a hollow cylinder. See figure (3-2). The thread in nut, tapped

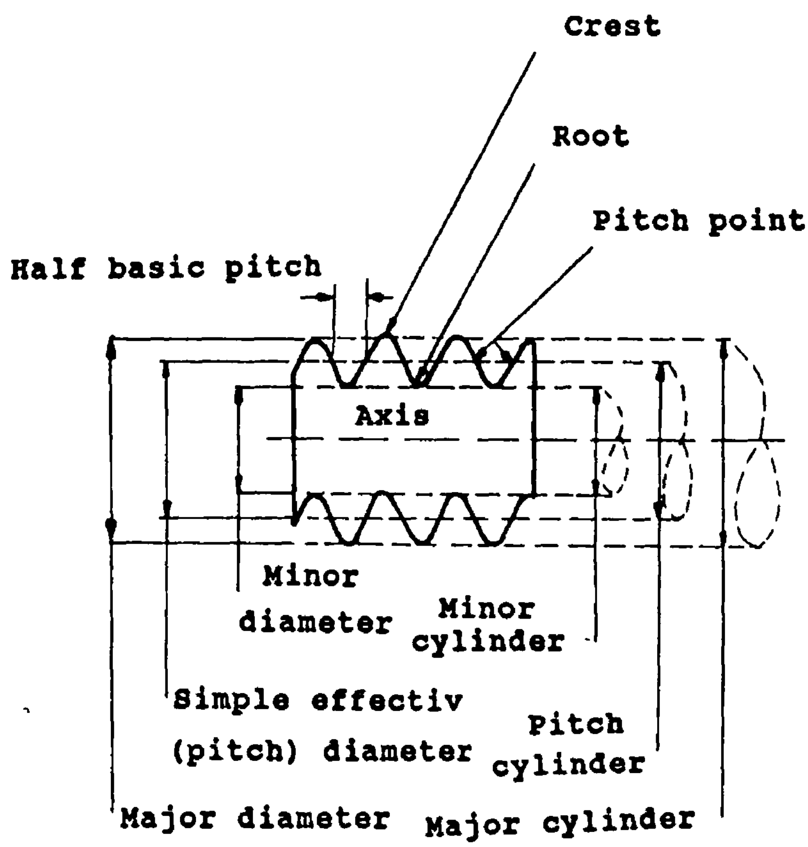


Figure (3-1)

External Screw Thread

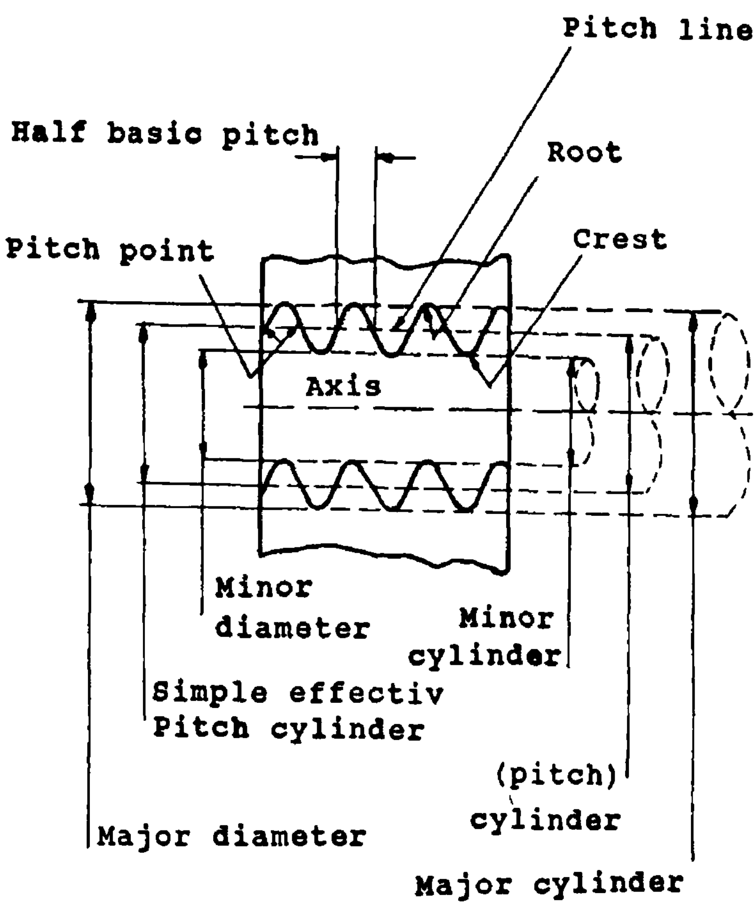


Figure (3-2)
Internal screw thread

holes or screw sockets are typical examples of internal screw threads.

(4)- RIGHT-HAND SCREW THREAD:

A thread which, if assembled with a stationary mating thread, recedes from the observer when rotated in clockwise direction, see figure (3-3).

(5)- LEFT-HAND SCREW THREAD:

A thread which,if assembled with a stationary mating thread, recedes from the observer when rotated in an anti-clockwise direction see figure (3-4).

(6)- PARALLEL SCREW THREAD:

A thread formed on the surface of a cylinder. See figure (3-1) and (3-2).

(7)- SINGLE-START SCREW THREAD:

A thread formed by a single continuous helical groove. See figures (3-3) and (3-4).

(8)- MULTI-START SCREW THREAD:

A thread formed by a combination of two or more helical grooves equally spaced along the axis. See figure (3-5).

3-1-2 Geometry of Screw Thread.

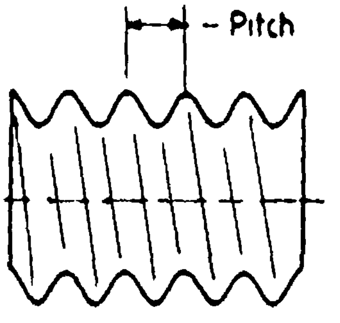


Figure (3-3)
Single-start screw thread
(Right hand)

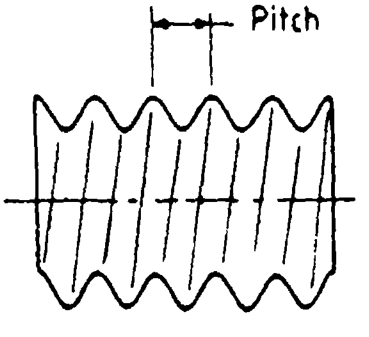


Figure (3-4)
Single-start screw thread
(left hand)

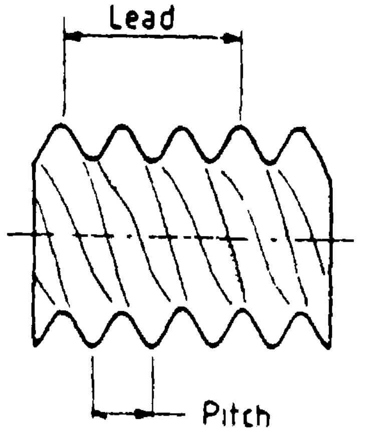


Figure (3-5)
Multi-start screw thread
(Triple-start right hand)

(1)- FORM:

The shape of one complete profile of the thread between corresponding points, at the bottom of adjacent grooves, as shown in axial plane section.

(2)- BASIC FORM:

The theoretical form on which the design forms for both the external and internal threads are based. See figures (3-6), (3-7) and (3-8).

(3)- DESIGN FORM:

The forms of the external and internal threads in relation to which the limits of tolerances are assigned. See figure (3-6).

(4)- FLANK:

Those parts of the surface on either side of the thread the inter-section of which with an axial plane are theoretically straight lines, see figure (3-7).

(5)- CREST:

That part of the surface of a thread which connects adjacent flanks at the top of the ridge. See figures (3-1) and (3-2).

(6)- ROOT:

That part of the surface of a thread which connects adjacent flanks at the bottom of the groove. See figures (3-1) and (3-2).

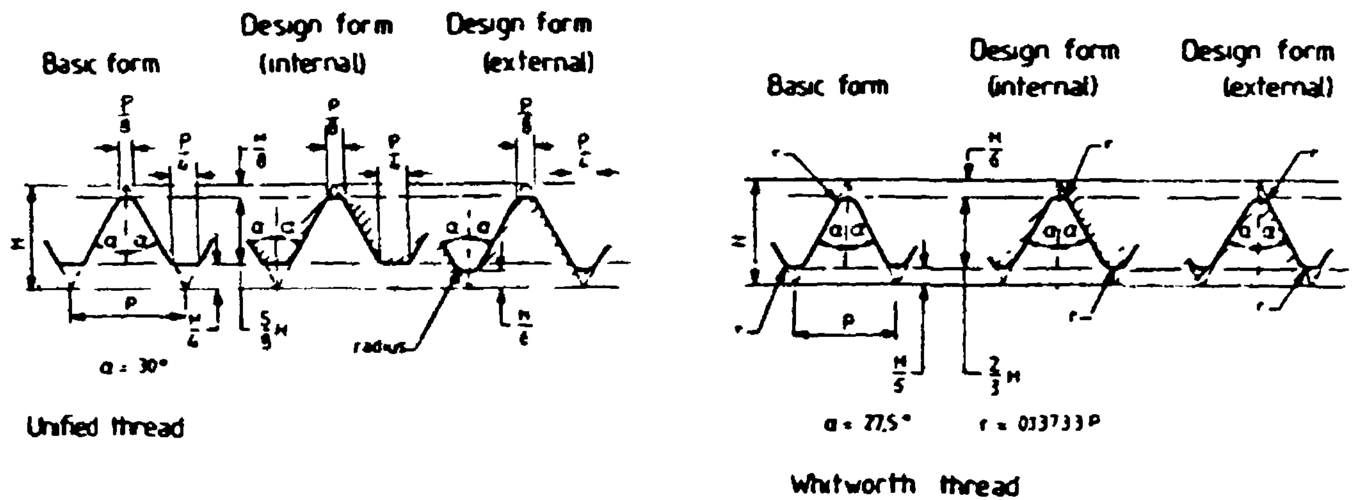


Figure (3-6)
Basic and design form of threads

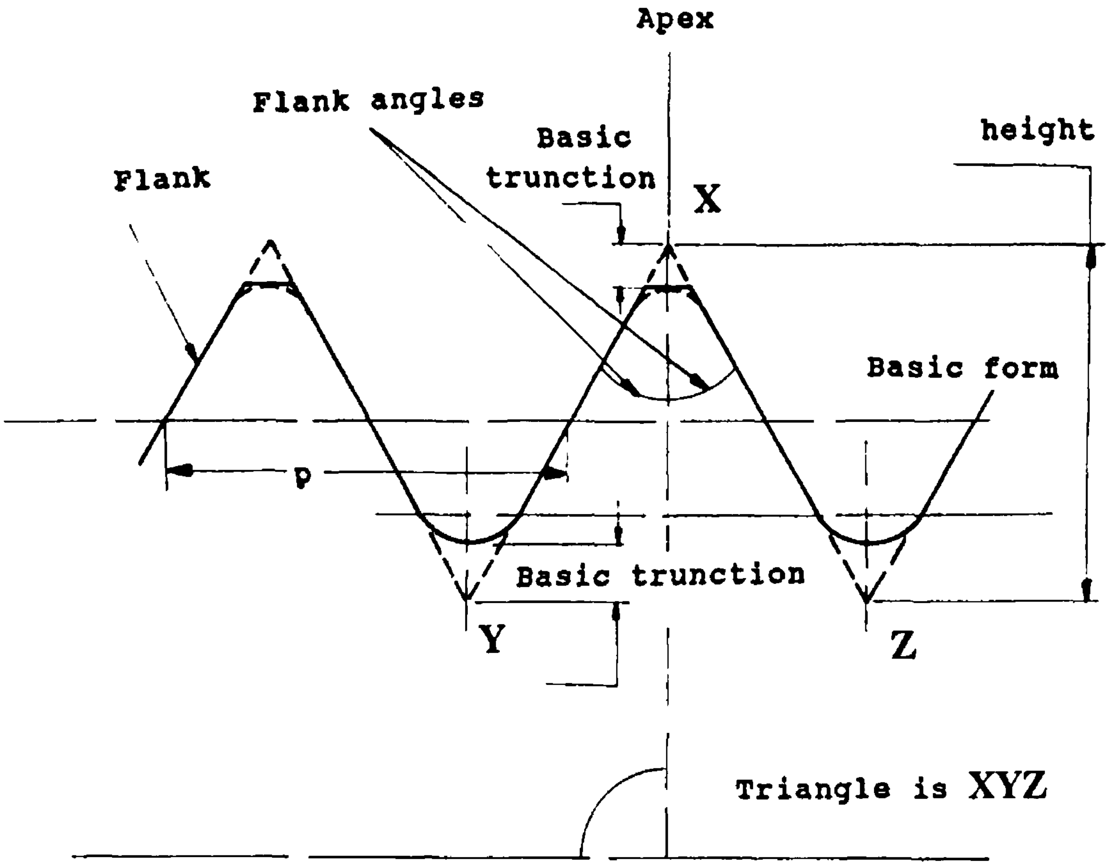


Figure (3-7)

Parrallel screw thread.

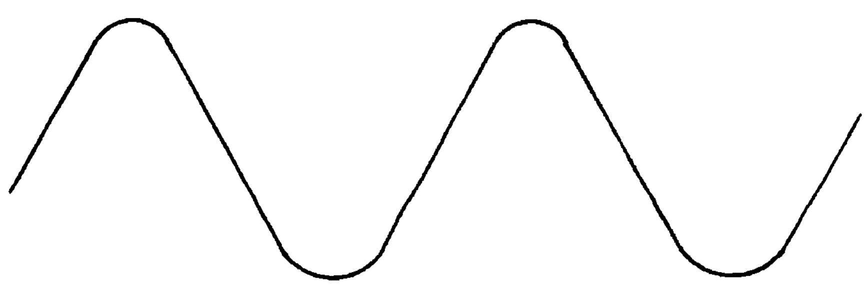


Figure (3-8)

Basic form

(7)- INCLUDED ANGLE (Angle Of Thread).

The angle between the flanks and the perpendicular to the axis of the thread measured in an axial plane section. See figure (3-7).

(8)- FUNDAMENTAL TRIANGLE:

A triangle of which two sides represent the form of a theoretical thread with sharp crest and roots, having the same pitch and flank angles as the basic thread form and whose third side, or base is parallel to a generator of the cylinder on which the thread is formed. See figure (3-7).

(9)- APEX:

The sharp corner of the fundamental triangle opposite to its base. See figure (3-7).

(10)- HEIGHT (OR DEPTH) OF THE FUNDAMENTAL TRIANGLE:

The distance, measured perpendicular to the axis from its apex to its base. See figure (3-7).

(11)-BASIC TRUNCATION:

The distance, measured perpendicular to the axis, between the basic major or minor cylinder and the adjacent apex of the fundamental triangle. See figure (3-7).

3-1-3 Pitch Of Screw Threads.

(1)- AXIS:

The axis of the pitch cylinder of a screw thread. See figures (3-1), (3-2) and (3-9).

(2)- PITCH:

The distance, measured parallel to the axis, between corresponding points on adjacent thread forms in the same axial plane section and on the same side of the axis. See figure (3-3), (3-4), (3- 5), (3-10) and (3-11).

(3)- LEAD:

The distance, measured parallel to the axis, between corresponding points on consecutive of the same thread helix in the same axial plane section and on the same side of the axis. See figure (3-5).

(4)- CUMULATIVE PITCH:

The distance, measured parallel to the axis of the thread between corresponding points on any two thread forms whether in the same axial plane or not.

(5)- PITCH CYLINDER:

An imaginary cylinder, co-axial with the thread, which intersects the surface of parallel thread in such a manner that the intercept on a generator of the cylinder between the points where it meets the opposite flanks of the thread groove is equal to half the basic of the thread. See figures (3-1) and

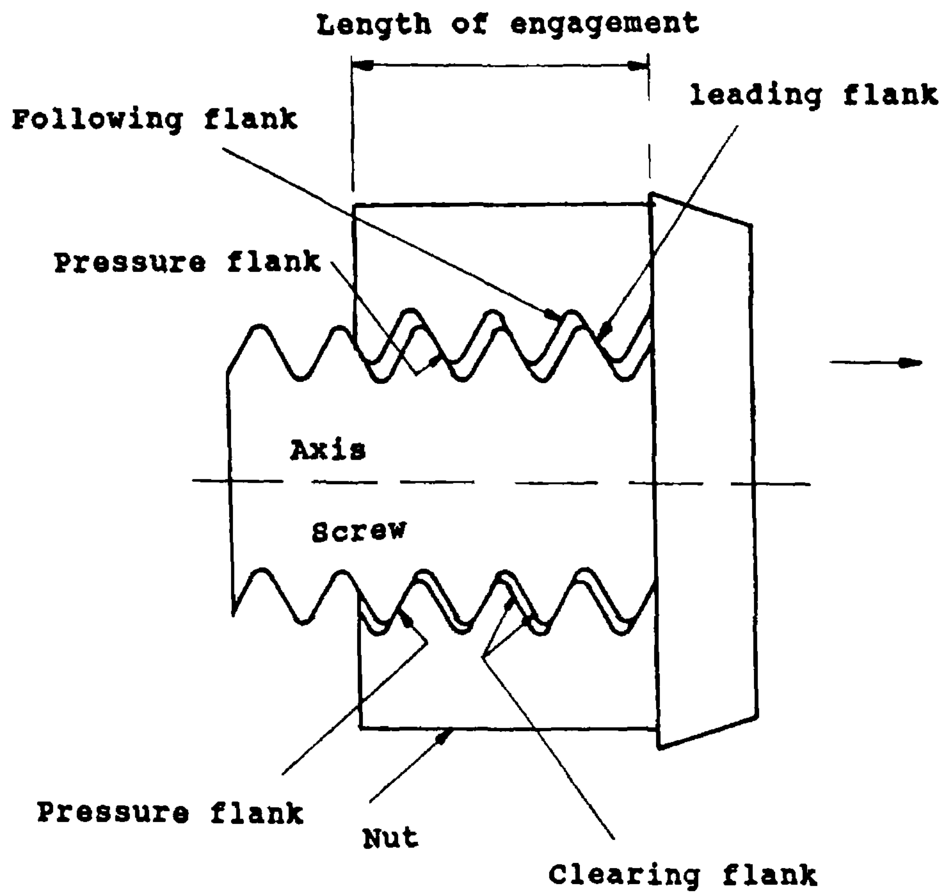

Length of engagement
leading flank
Following flank
Pressure flank
Axis
Screw
Pressure flank
Nut
Clearing flank

Figure (3-9)

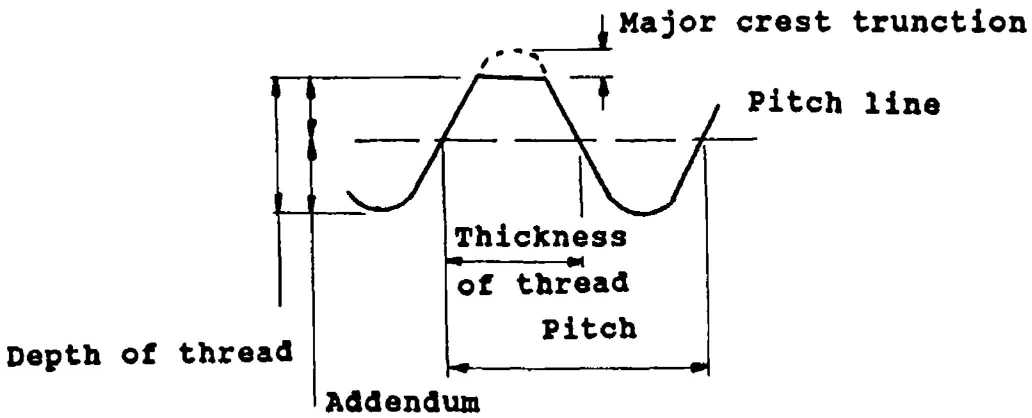


Figure (3-10)

Design form (external thread)

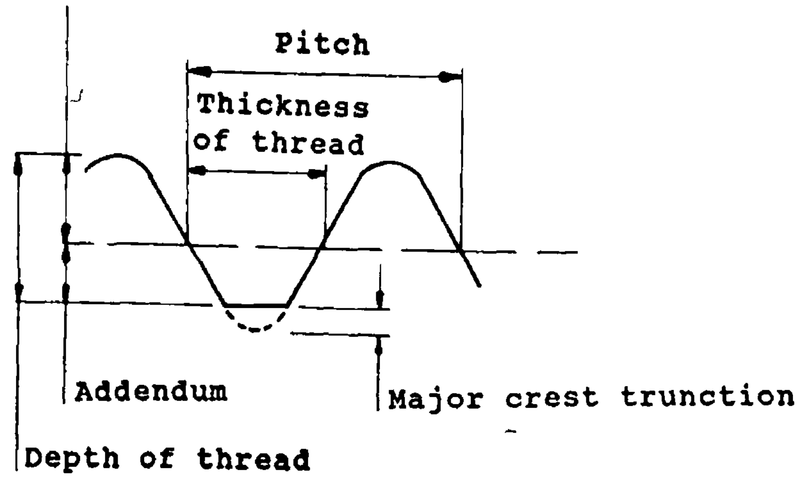


Figure (3-11)

Design form

(internal thread)

(3-2).

(6)- PITCH LINE:

The generator of the pitch cylinder. See figures (3-1), (3-2), (3-10) and (3-1).

(7)- PITCH POINT:

The point where the pitch line intersects the flank of the thread. See figures (3-1), (3-2).

(8)- LEAD ANGLE:

On a parallel thread the angle made by the helix of the thread at the pitch with a plane perpendicular to the axis.

3-1-4 Diameter Of Screw Threads.

(1)- MAJOR CYLINDER:

An imaginary cylindrical surface which just touches the crests of an external thread or the roots of an internal thread. See figures (3-1) and (3-2).

(2)- MINOR CYLINDER:

An imaginary cylindrical surface which just touches the roots of an external thread or the crests of an internal thread. See figures (3-1) and (3-2).

(3)- MAJOR DIAMETER:

The diameter of the major cylinder of a parallel thread, in a specified plane normal to the axis. See figures (3-1) and (3-2).

(4)- EFFECTIVE (OR PITCH) DIAMETER:

The diameter of the pitch cylinder of a parallel thread in a specified plane normal to the axis. See figures (3-1) and (3-2).

(5)- VIRTUAL EFFECTIVE DIAMETER:

The effective diameter of an imaginary thread of perfect pitch and flank angle, having the full depth of flanks, but clear at the crests and roots, which would just assemble with the actual thread over the prescribed length of engagement.

3-1-5 Assembly of Screw Threads.

Definitions of terms relating to assembly of screw threads are given in **BS: 2517**, [25].

3-2 Type of Screw Threads

Eleven types, or series, of threads are of commercial importance, several having equivalent series in the metric system and unified systems:

(1)- Coarse-thread series (UNC and NC). For general use where not subjected to vibration.

(2)- Fine-threads series (UNF and NF). For most automotive and aircraft work.

(3)- Extra-fine series (UNEF and NEF). For use with thin-walled material or a maximum number of threads are required in a given length.

(4)- Eight-thread series (8 UN and 8 N). Eight threads per inch for all diameters from 1 through 6 in. It is used primarily for bolts on pipe flanges and cylinder-head studs where an initial tension must be set up to resist steam or air pressures.

(5)- Twelve-thread series (12 UN and 12 N). Twelve threads per inch for diameter for 1/2 through 6 in. It is not used extensively.

(6)- Sixteen-thread series (16 UN and 16 N). Sixteen threads per inch for diameters from 3/4 through 6 in. It is used for a wide variety of applications that require a fine thread.

(7)- American Acme thread. See figure (3-12).

(8)- Buttress thread.

(9)- Square thread.

(10)- 29^0 Worm thread. These last four of the threads are used primarily in transmitting power and motion.

(11)- American standard pipe thread. This thread, shown in figure (3-12), is the standard tappered thread used on pipe joints in this country.

The taper on all pipe threads is 3/4 in. per foot. The unified threads are available in a coarse (UNC and NC), fine (UNF and NF), extra-fine (UNEF and NEF), and three-" pitch " (8, 12 and 16) series, the number of threads per inch being according to an arbitrary determination based on the major diameter.

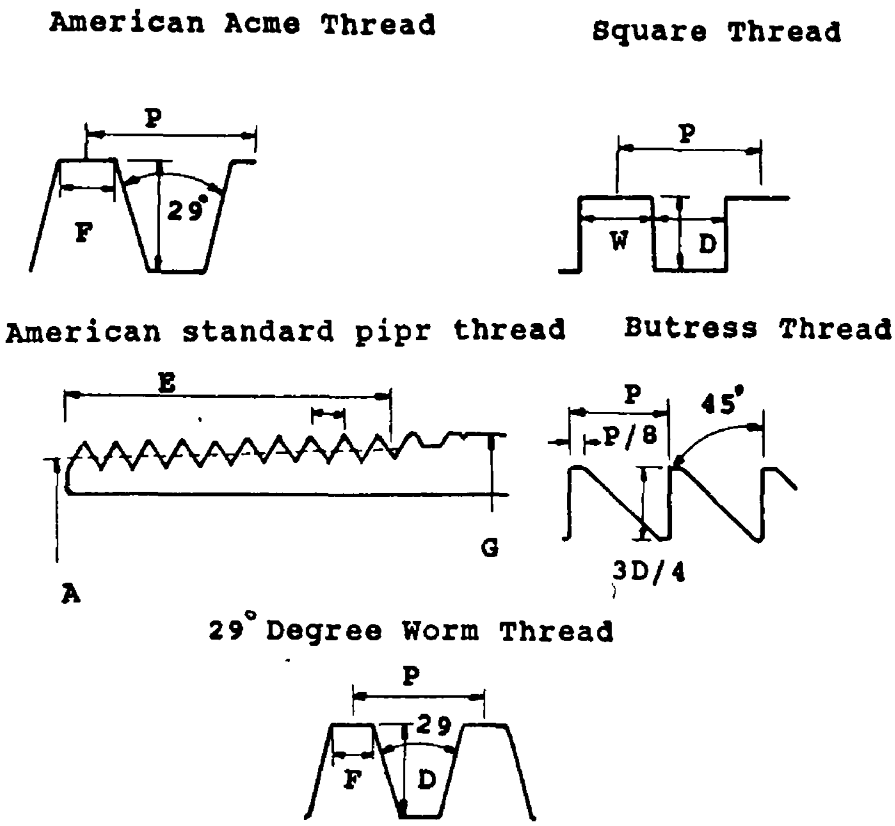


Figure (3-12)

Special thread forms.

Many nations have now adopted **ISO** threads into their national standards. Besides metric ISO threads, there are also inch-based **ISO** threads, namely the UN series with which people in the United States, Canada, and Great Britain are familiar.

ISO offers a wide range of metric sizes. Individual countries have the choice of accepting all or a selection of the ISO offerings. For a comparison of unified and **ISO** threads sizes see table (3-1), [7].

The biggest difference between the UN and ISO series is the number of threads per unit length. The design profiles for the UN and ISO are shown in figure (3-13).

While many features are the same, principal difference are related to basic size,the magnitude and application of allowance and tolerances, and thread designations. For the UN thread, a flat root is specified for external threads; however in practice, product threads are produced with partial or completely rounded crests.

In the internal UN threads, it is necessary to provide for some threading tool crest wear. The ISO forms, in figure (3-13), are shown with and without an allowance on the external thread, and tool wear, as indicated by a form clearance, is permissible [42].

3-3 Methods Of Manufacturing Threads.

External threads may be produced by the following manufacturing processes:

TABLE (3-1)

Comparison between selection Unified and ISO Threads.

Unified				ISO	
D		Thread per in.		Thread per in.	
Number in.	mm	UNC	UNF	Coarse	Fnie
#2	2.18	56	64	M2x.4	
#4	2.84	40	48	M2x.45	
#8	4.17	32	36	M4x.7	
#10	4.82	24	28	M5x.8	
1/4 in.	6.35	20	28	M6x1	
1/2 in.	12.7	13	20	M12x1.75	M12X1.25
3/4 in.	10.05	10	16	M20X2.5	M20X1.5
1 in.	25.4	8	14	M24X3	M20X2

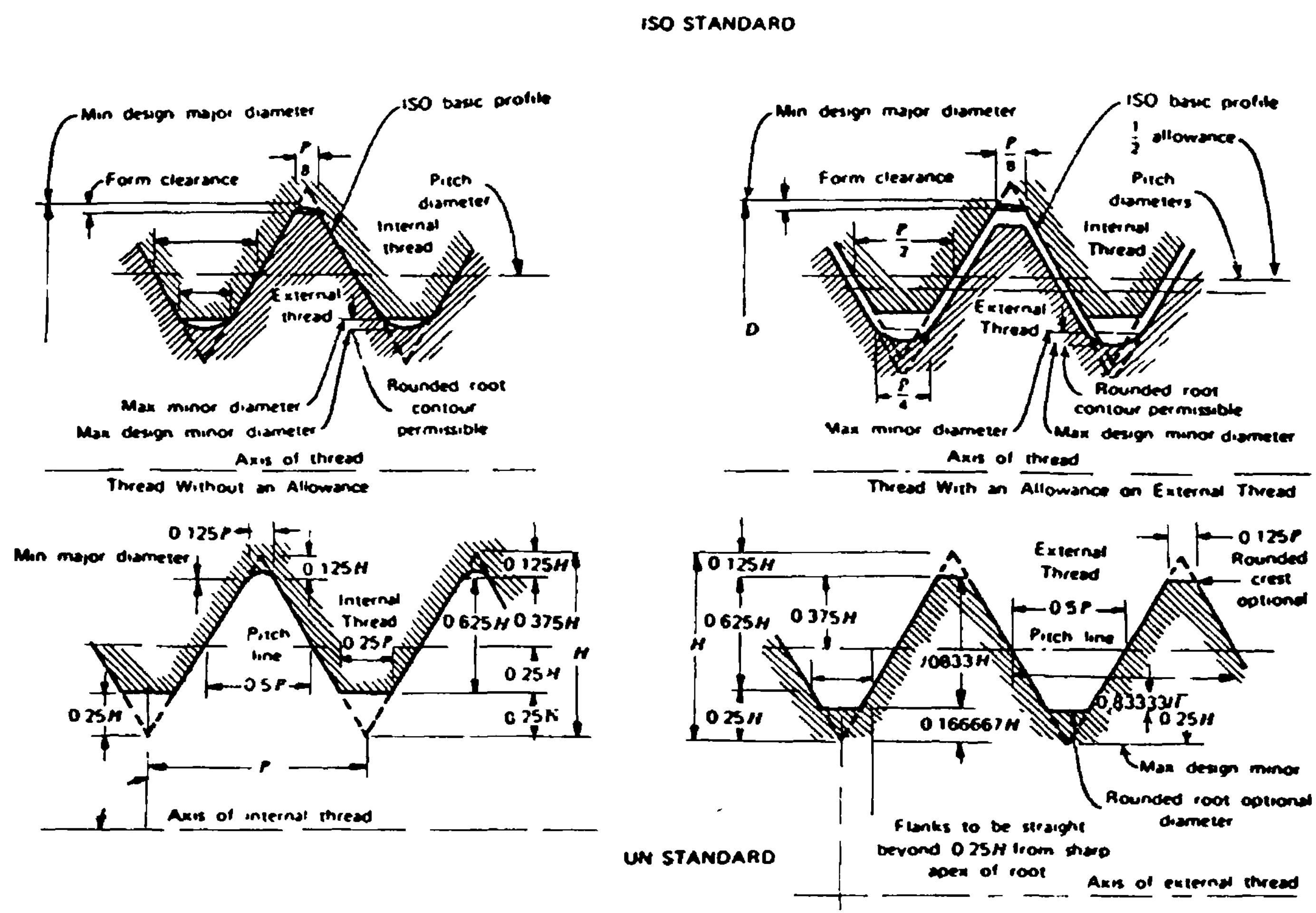


Figure (3-13)
Design profile of ISO and UN thread standard

(1)- Cutting to shape on engine lathe.

(2)- Using die and stocK (manual).

(3)- Automatic die head (turret lathe).

(4)- Milling machine.

(5)- Threading machine (plain or automatic).

(6)- Rolling between dies (flat or circular).

(7)- Die casting.

(8)- Grinding.

Internal threads may be produced by:

(1)- Cutting to shape on an engine lathe.

(2)- Using tap and holder.

(3)- Automatic collapsible tap.

(4)- Milling machine.

(5)- Screw broach.

3-3-1 Cutting screw threads on a lathe.

The lathe is usually selected when only a few threads are to be cut or when special forms are desired [42].

Cutting screw threads on a lathe is a slow, repetitions process that requires considerable operator skill. The cutting speeds usually employed are from one third to on half of regular speeds to enable the operator to have time to manipulate the controls and to ensure better cutting. The cost per part can be high, which explains why other methods are used when ever possible [7].

3-3-2 Taps and Dies.

Taps are used principally for the manual production of internal threads. The tool itself is a hardened piece of carbon or alloy steel resembling a bolt, with flutes cut along the side to provide the cutting edge.

For hand tapping, these are furnished in sets of three for each sizes. In starting the thread, the taper tap should be used, since it insures straighter starting and more gradual cutting action on the threads. If it is a through hole, no other tap is needed. For closed or blind holes with threads to the very bottom, the taper, and bottoming taps should all be used in the order named. Other taps are available and are named according to the kind of thread they are to cut.

To cut external thread, the most common method is by the adjustable die. It can be made to cut either slightly undersize or oversize. When used for hand cutting, the die is held in a die stock which provides the necessary leverage to turn the die in making the cut.

For successful operation of either taps or dies, consideration must be given to the nature of the material to be threaded. No tool can be made to work successfully for all materials.

The shape and angle of the cutting face also influence the performance. Another important factor is proper lubrication of the tool during the cutting operation; this insures longer life of the edges and results in smoother threads.

Taps and dies can also be used in the machine cutting of threads. Because of the nature of the cutting operation, they must be held in special holder, so designed that the tap or die can be withdrawn from the work without injury to the threads. This is frequently accomplished by reversing the rotating of the tool or work after the cut has been made.

In *small-production* work on a turret lathe, the tap is held by a special holder, which prevents the tap from turning as the thread are cut. Near the end of the cut the turret holding the tool is stopped, and the tap holder continues to advance until it pulls away from a stop pin a sufficient amount to allow the tap holder to rotate with the work. The rotation work of the work is then reversed and, when the tap holder is withdrawn, it is again engaged with the stop and held until the work is rotated from the tap .

External threads can be cut with a die utilizing this same procedure although in most cases such threads are cut with self-opening dies.

3-3-3 Thread Chasing

In production work self-opening dies and collapsible taps are used to eliminate back tracking of the tool and to save time. The tools have individual cutter dies, known as chasers, mounted in appropriate holder, which are capable of adjustment or replacement. With chasers more accurate work results, the cutters can be kept in proper adjustment, and there is no danger of damaging the cut thread as the tool is withdrawn.

In some cases the tool is held stationary and the work revolves in others the reverse procedure may be used. All precision screws require a lead screw feed to obtain accuracy.

Two types of automatic die heads are used. In one cutters or chasers are mounted tangentially. In the other they are in a radial position. Radial cutters can be changed quickly; consequently, they are used for threading materials that are hard to cut. The die head commonly used on most turret lathes is of stationary type. The work rotates and the chasers open automatically at the end of the cut so that they can withdraw from the work without damage.

In threading machines, the dies rotate and the work is fed to them, but otherwise the operation is the same.

3-3-4 Tapping Machine

Although much tapping is done on drill presses equipped with some form of tapping attachment, most production tapping is done on specially constructed automatic machines. Nuts to be threaded are fed from an oscillating hopper to the working position; the spindles are reversed at double the tapping speed; and the nuts are discharged to individual containers.

A common type of tapping machine has multi-spindle arrangement provided with taps having extra long shanks.

The tap is advanced through the nut by the lead screw and, upon completion of the threading, continues downward until the nut is released.
The spindle then returns to its upper position with the tapped nut on its shank. When the shank has been filled with nuts, the tap is removed and the nuts are emptied into a container.

3-3-5 Thread Milling.

Accurate threads of large size, both external and internal, can be cut with standard or hob-type cutters. For long external threads, a threading machine similar in appearances to a lathe is used. Work is mounted either in a chuck or between centres, the milling attachment being at the rear of the machine.
In cutting a long screw, a single cutter is mounted in the plane of the thread angle and fed parallel to the axis of the threaded part. The feed (f) in thread milling is expressed as the cutter advance per tooth, or millimetre per cutter tooth by the following formula:

$$\mathbf{f = 3.14\ d.s/n.N} \qquad \mathbf{(3 - 1)}$$

From this expression it is evident that the cutter load per tooth, which varies directly with the feed, can be changed by varying the cutter speed, work speed, or number of teeth in the cutter.
This permits reducing the load on the cutter teeth so

that deep threads can be cut in one pass. For short external threads, a series of single-thread cutter are placed side-by-side and are made as one cutter, having a width slightly more than that of the thread to be cut. The cutter is fed radially into the work to the proper depth and, while rotating a little over one revolution, completes the milling of the thread. Proper lead is obtained by a feed mechanism which moves the cutter axially while it is cutting.

Milling machines of the planetary-type are also used for mass production of short internal or external threads. The milling head carrying the hob is revolved eccentrically about the rigidly held work, which is rotated simultaneously on its own axis. It is advanced by means of a lead screw for a sufficient distance to produce the thread [42].

3-3-6 Thread Rolling

Thread rolling is used to produce threads in substantial quantities. This is a cold-forming process operation in which the threads are formed by rolling a thread blank between hardened dies that cause the metal to flow radially into the desired shape. Because no metal is removed in the form of chips, less material is required, resulting in substantial savings.

In addition, because of the cold working, the threads have greater strength than cut threads, and a smoother, harder, and more wear-resistant surface is obtained. In addition, the process is fast, with production rate of one per second being common.

The quality of cold-rolled (or fluteless-tapped) products is consistently good and tap life is greater than that of HSS machine taps.

Chipless operations are cleaner and there is a savings in material (15% to 20% saving in blank stock weight is typical), [7].

Figure (3-14) illustrating stock material saving of rolled threads over cut threads. Also figure (3-15), the blank diameters for both rolled and cut threads are indicated for several threads [42]. Thread rolling is done by four basic methods.

The simplest of these employs one fixed and one movable flat rolling die, as illustrated in figure (3-16). After the blank is placed in position on the stationary die, movement of the moving die causes the blank to be rolled between the two dies and the metal in the blank is displaced to form the threads. As the blank rolls, it moves across the die parallel with its longitudinal axis. Prior to the end of the stoke of the moving die, the blank rolls off the end of the stationary die, its thread being completed.

One obvious characteristic of a rolled thread is that its major diameter always is greater than the diameter of the blank. When an accurate class of fit is desired, the diameter of the blank is made about 0.002 in. larger than the thread-pitch diameter.

If it is desired to have the body of a bolt larger than

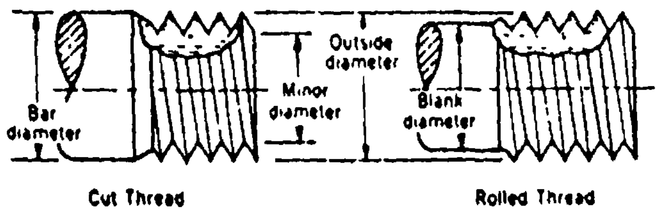


Figure (3-14)
Stock material saving of roled threads over cut threads

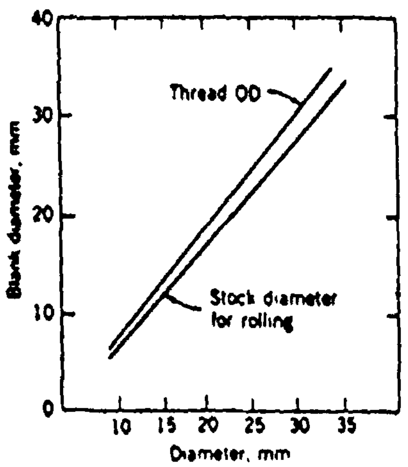


Figure (3-15)
Blank diameter for rolled and cut threads

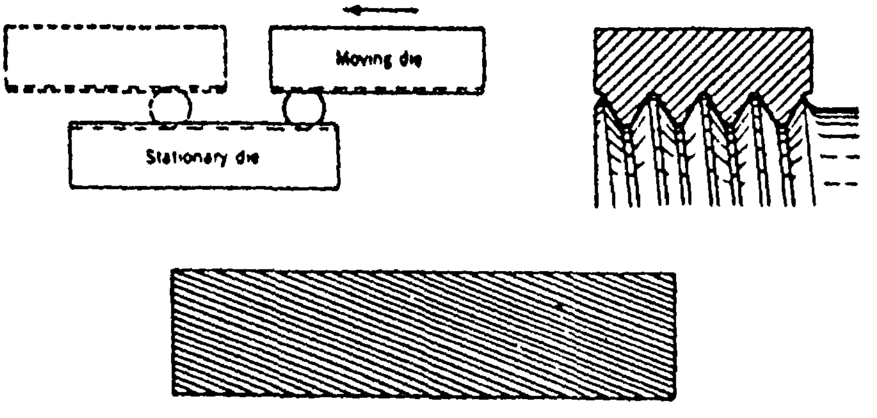


Figure (3-16)
Principle of rolling threads
with flat dies

the outside diameter of the rolled thread, the blank or the thread is made smaller than the body.

Thread rolling can be done with cylindrical dies. There are three-roll methods commonly employed on turret lathes and screw machines. Two variation are used. In one, the rolls are retracted and the blank is placed in position. They then move inward radially, while rotating, to form the thread.

More commonly the three rolls are contained in a self-opening die head similar to the conventional type used for cutting external threads. The die head is fed onto the blank longitudinally and forms the thread progressively as the blank rotates. With this procedure, as in the case of cut threads, the innermost 1.5 to 2 threads are not formed to full depth because of the progressive action of the rollers.

The two-roll method is commonly employed for automatically producing large quantities of externally threaded parts up to 6 in. diameter and 20 in. in length. The planetary type machine is for mass production of rolled thread on diameter up to 1 in.

Not only is thread rolling very economical, but the threads are excellent as to form and strength. [7].

Following are some of the advantages of the thread rolling process:

(1)- Improve tensile, shear, and fatigue strength.

(2)- Smooth surface finish of 0.1 to 0.8 um.

(3)- Close accuracy maintained.

(4)- Less material required.

(5)- Cheaper materials may often be used owing to improvement of physical properties.

(6)- High production rate.

(7)- A wide variety of thread forms possible.

Limitations of the thread rolling process include:

(1)- Blank tolerance must be close, since no metal is removed.

(2)- Not economical for short run jobs.

(3)- Only external threads can be rolled.

(4)- Material having a hardness exceeding Rockwell C 37 cannot be rolled [42].

3-3-7 Thread Grinding.

Grinding can produce very accurate threads, and it also permits threads to be made on hard materials. Three basic methods are used. Centre-type grinding with axial feed is the most common method, being similar to cutting a thread on a lathe.

A shaped grinding wheel replaces the single-point tool. Usually, a single-ribbed grinding wheel is employed, but multiple-ribbed wheels are used occasionally.

The grinding wheels are shaped by special diamond dressers or by crush dressing and must be inclined to the helix angle of the thread. Wheel speeds are in the high range. Several passes are usually required to complete the thread. Centre-type in feed thread grinding is similar to multiple-form milling in that a multiple-ribbed wheel, as wide as the length of the desired thread, is used.

The wheel is fed inward radially to full thread depth, and the thread blank is then turned through about 1.5 turns as the grinding wheel is fed axially a little more than the width of one thread.

centre-less thread grinding, is used for making headless set screw. A production rate of 60 to 70 screws of 1.5 inch length per minute is possible [7], [42].

The crest forms resulting from different production methods are illustrated in figure (3-17), [43].

3-4 Errors of screw threads

A screw thread has seven elements, error on any one of which may be sufficient to reject work which ought to pass. These elements are:

(1)- Major diameter.

(2)- Minor diameter.

(3)- Effective (or pitch) diameter.

(4)- Pitch.

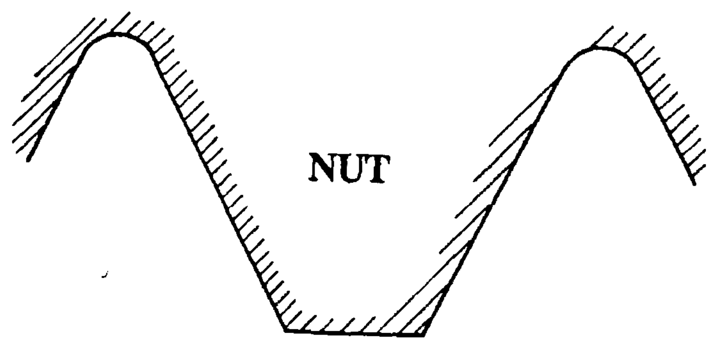
(5)- Flank angles.

(6)- Radius at crest.

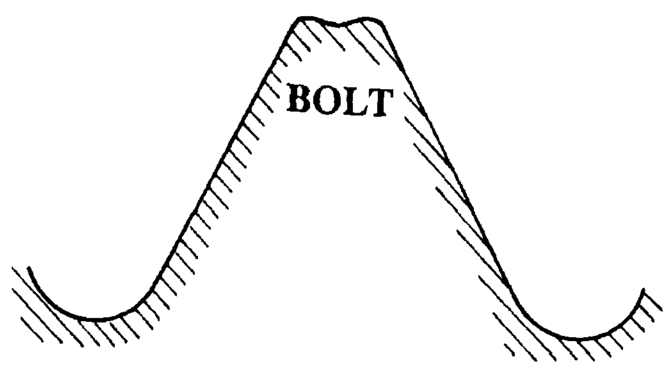
(7)- Radius at root.

Of these, effective diameter, pitch and flank angle are, perhaps, the most critical, and are those which errors most frequently occur.

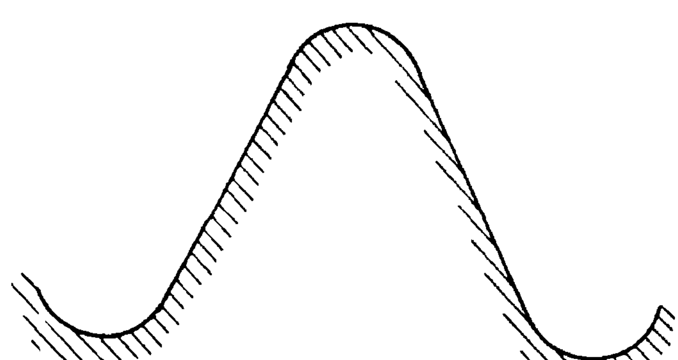
3-4-1 Effective Diameter



(A)- Typical crest on tapped nut



(b)- Typical crest on rolled bolt



(C)- Typical crest on cut thread bolt

Figure (3-17)

Crest forms resulting from different

prodution methods

The importance of accuracy in the effective diameter of a screw thread becomes evident when it is realized that error in this diameter determine to a large extent the amount of " play" between mating screw threads.

3-4-2 Pitch

The effect of error in pitch upon the fitting together of screw threads depends not so much on the individual errors in the spacing of the adjacent turns of thread as on the additive effect of these errors, which is known as the cumulative error.

The cumulative pitch error of a screw thread is the error of its effective diameter helix, measured parallel to the axis of the screw thread, from its correct position in relation to a fixed datum plane normal to the axis of thread. Figure (3-18) is a chart showing the cumulative error along the whole length of the helix of a thread. A chart of the cumulative pitch error may exhibit certain characteristics depending on the nature of the error and its causes.

The error may be of a repetitive or periodic nature, i.e. it may vary in magnitude along the length of thread and recur at regular intervals. If the error recurs at intervals of one turn then the screw is said to be " drunken ".

Pitch errors of a periodic nature are usually due to some float or faults in the rotating members of the machine on

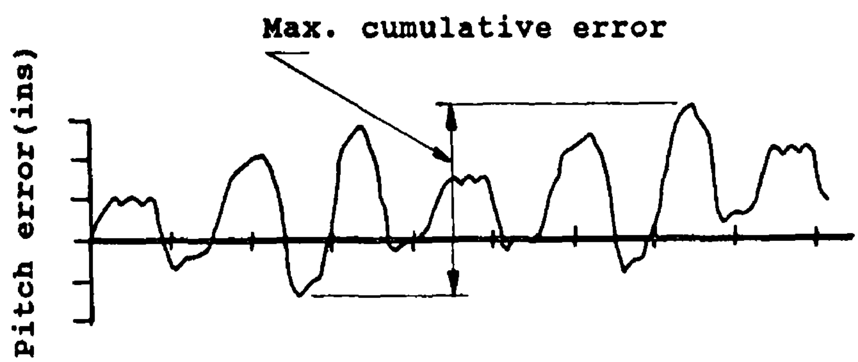


Figure (3-18)

Chart of cumulative pitch error

of periodic character

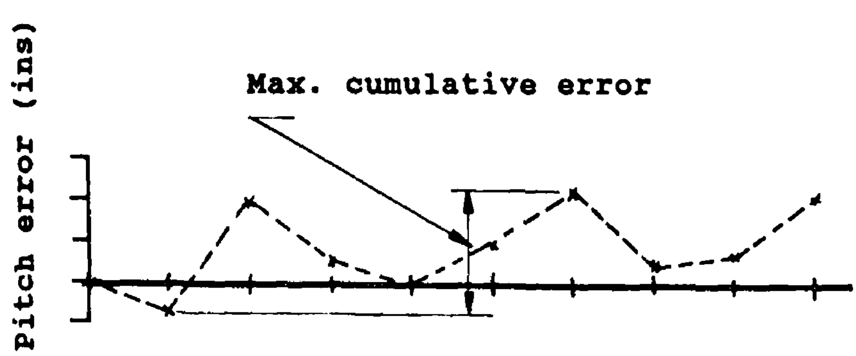


Figure (3-19)

Chart of cumulative pitch error measured

at interavel of one pitch

which the screw thread is produced. Common sources of such errors are lack of truth in the thrust-collar of the lead screw and its a butment face, or eccentric mounting of the gears in the train connecting the lead screw and headstock spindle.

Defects of both these types produce sinusoidal pitch error curves. If more than one gear is eccentric the pitch error curve will be the resultant of a number of sinusoidal curves and may be complex in character as shown in figure (3-18).

The chart of the cumulative pitch error of a screw thread may indicate that the pitch error varies irregularly along the length of the thread. Such errors may be due to other faults in the machine on which the screw thread was produced, or possibly to an irregular cutting action due to non-uniformity of the material of the screw thread.

Errors of a periodic or irregular type such as those described above may be superimposed on a cumulative pitch error of a more or less uniform nature caused, for example, by an axial extension or contraction of the screw due to hardening, errors in the pitch of the lead screw or lack of straightness of the ways of the saddle.

To obtain a complete knowledge of the cumulative pitch error of a screw thread necessitates measuring the error of the effective diameter helix of the thread from one end of the thread to the other. It is rarely convenient or practicable to do this, however and it is usual to measure the errors at intervals of whole pitches along a line parallel to the axis of the thread.

Where appreciable pitch errors of a periodic or erratic nature are present in a thread this method of measurement does not provide a true guide to the full magnitude of the pitch error. Thus, if measurements were made at intervals of single turns of the thread of the screw to which figure (3-18) refers, the result would be a chart as in figure (3-19), where the true character of the error is no longer seen and the maximum cumulative error.

3-4-3 Error in pitch in relation to effective diameter.

It is important to realize that any error in pitch needs to be compensated by a corresponding, but independent, error in effective diameter. Thus, if an otherwise perfect external screw has pitch error, it will not screw into a perfect internal screw of the same nominal size.

It can be made to do so by reducing its effective diameter and so making the threads slightly thin. Thus, if any error in pitch is present, the " virtual " effective diameter of an internal screw will be greater, and of an external screw less, than its actual (simple) effective diameter. The equivalent difference in effective diameter necessary to compensate for any given pitch error may be determined as follows:

Suppose the full and the dotted outlines in figure (3-20) represent respectively an otherwise perfect external screw having a pitch error (dp) and a perfect internal screw which will just assemble with the external screw over its entire length of thread.

The external and internal screw threads will be contact with each other only on the two flanks at the extreme ends of the thread. The radial displacement between the mating screw threads will be ($dp/2 \cot \alpha$), where (α) is the flank angle of the thread. In other words the equivalent difference in effective diameter necessary to compensate for a relative pitch error (dp) between mating threads is equal to ($dp \cot \alpha$).

The numerical values of the factor ($\cot \alpha$) for the standard forms of threads in common use are as follows:

	2 α	**Value of Cot α**
Whitworth thread	**55 °**	**1.921**
British Association thread	**47.5 °**	**2.273**
Unified thread	**60 °**	**1.732**
Metric system international	**60 °**	**1.732**
British standard cycle thread	**60 °**	**1.732**
Acme thread	**90 °**	**3.867**

The tables in appendix (A3-1), give for screws of various thread form the virtual differences in effective diameter corresponding to errors in pitch rising in steps of or 0.000 05 in. up to 0.001 in.

3-4-4 Error in angle in relation to effective diameter.

Figure (3-21), illustrates how the presence of errors in the angles of the flanks of an external screw threads must be accompanied by a corresponding reduction

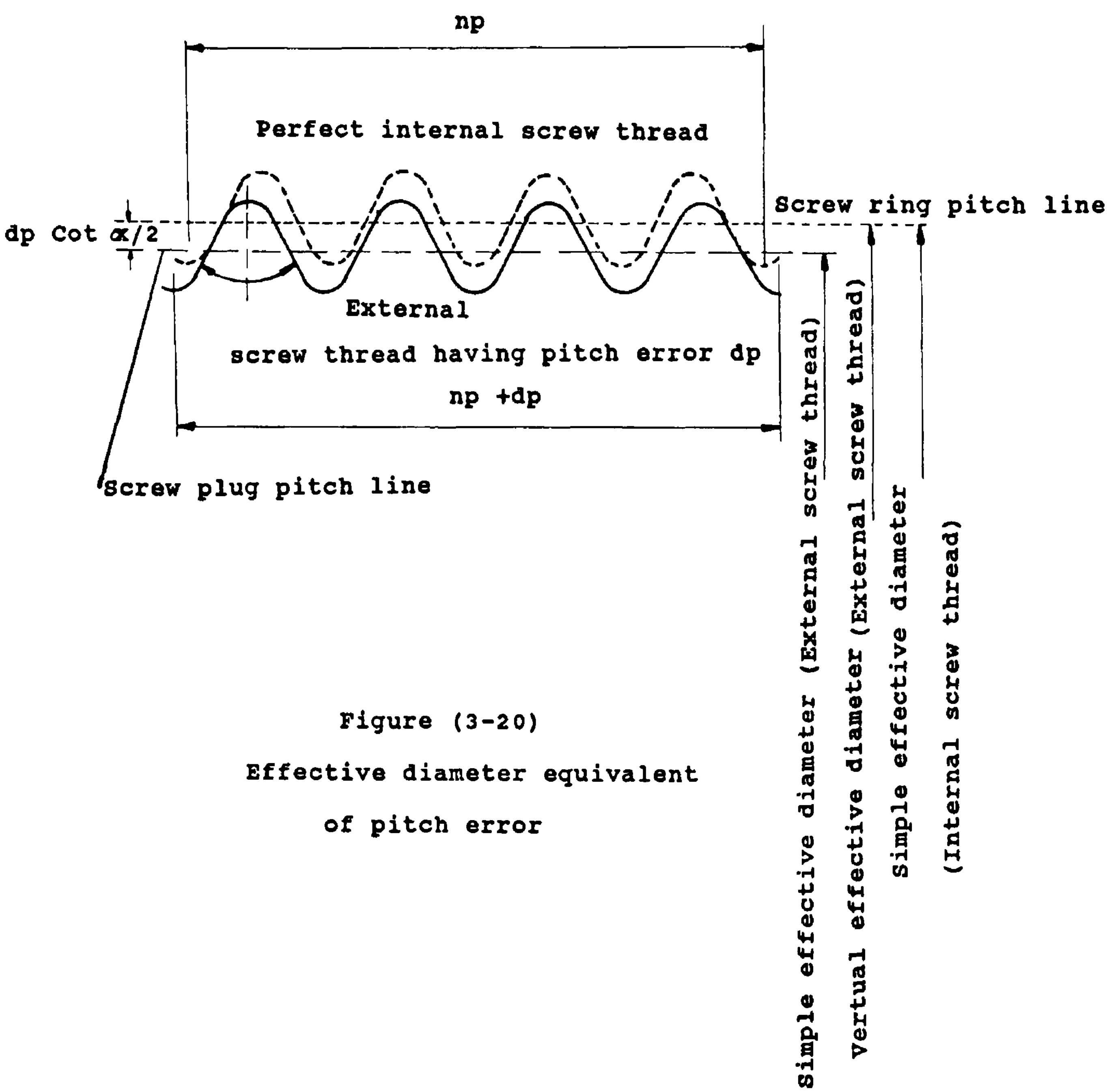


Figure (3-20)

Effective diameter equivalent

of pitch error

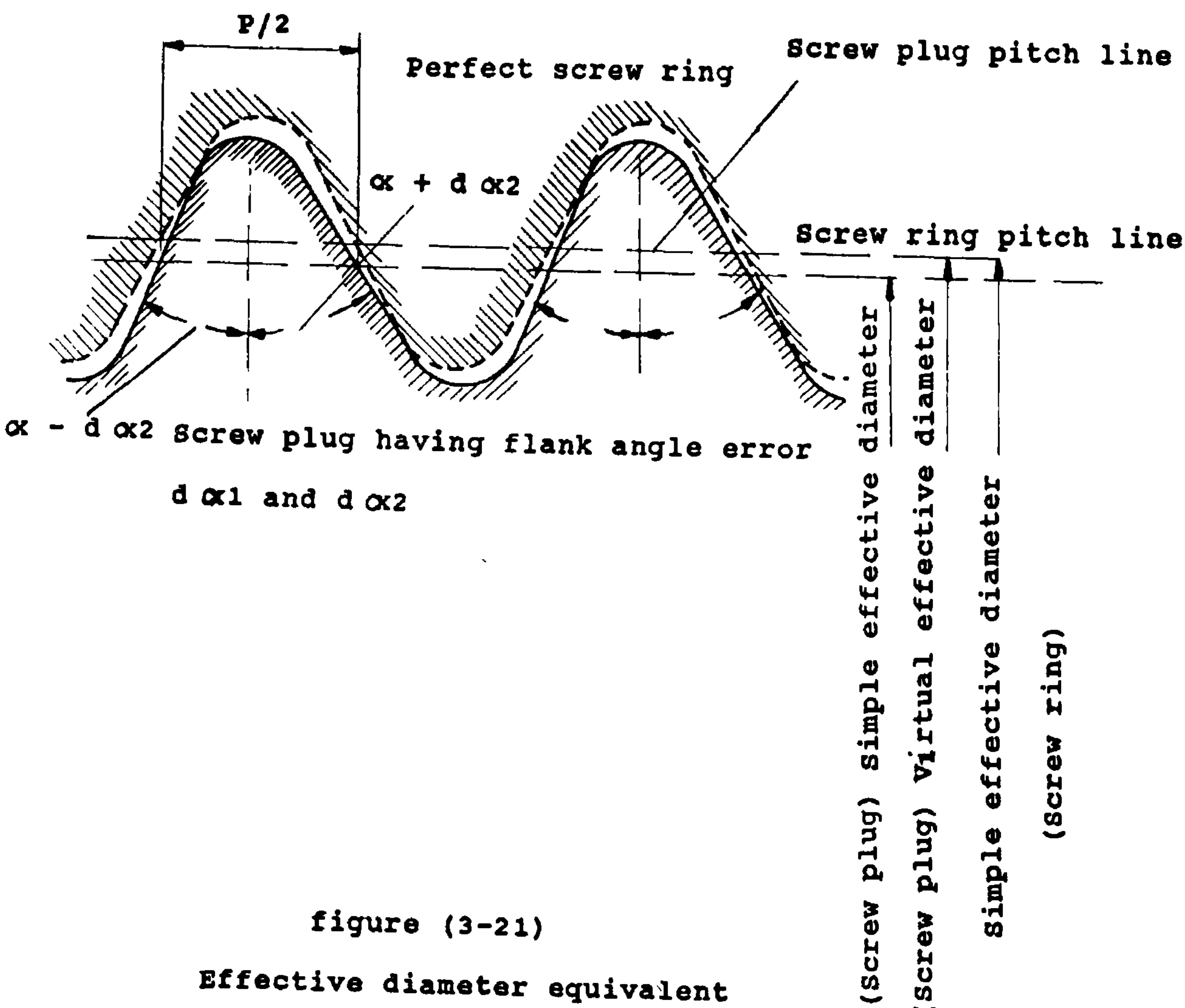


figure (3-21)

Effective diameter equivalent

of flank angle error

in the effective diameter, if the screw is to " fit " a prefect internal screw thread of the same nominal size. If ($d\alpha_1$) and($d\alpha_2$) represent the errors present in the two flank angles of a screw thread, the corresponding virtual increase (decrease) in the effective diameter of the thread in the case of an external (internal) screw thread is given by the following approximate expressions

	Virtual change in effective Diameter
Unified threads.............	**0.0109 xpx ($d\alpha_1+d\alpha_2$)**
Whitworth thread...........	**0.0105 xpx ($d\alpha_1+d\alpha_2$)**
British association thread.	**.0.0091 xpx ($d\alpha_1+d\alpha_2$)**
British standard metric thread..	**0.0015 xpx ($d\alpha_1+d\alpha_2$)**
British standard cycle thread..	**.0.0074 xpx ($d\alpha_1+d\alpha_2$)**
Acme thread...............	**.0.0180 xpx ($d\alpha_1+d\alpha_2$)**

The measured simple effective diameter of a screw threads should lie between the limits specified for the effective diameter and:

(a)- For external threads. The computed virtual effective diameter should not be greater than the maximum limit of effective diameter.

(b)- For internal threads. The computed virtual effective diameter should not be less than the minimum limit of effective diameter.

3-4-5- Radii at crest and root.

Errors in the radii at the crests and root of screw threads, particularly of gauges, are frequently of great consequence, as they may lead to the presence of superfluous metal or vice versa. Such defects may prevent a gauge from functioning satisfactorily, even though the measured values of the major, effective, and minor diameter are correct.

3-5 Control of accuracy of pitch.

When high accuracy of pitch is required, and the work is threaded by taps, thread cutting dies, chasers, milling hobs or thread rolling dies, then the threads on these forming tools should be ground.
Accuracy of pitch is also obtained if the screw threads on the work are produced by grinding. If screw threads are cut on a lathe, then particular attention should be given to the accuracy of pitch of the lathe used.
Trends in lathe design have been towards ease and quickness of gear changing and modern lathes can be set to cut almost any standard pitch by moving a few levers, thus increasing the sources of possible error.
Inaccuracy in the pitch of screw gauges is generally due to one or more of the following :

(a)- Errors introduced during the process of threading.

(b)- Distortion of the steel during hardening.

(c)- Errors introduced in the process of final lapping to size.

(d)- Secular changes in the hardened steel.

With modern lathes errors of a periodic or erratic character are most commonly attributable to errors in the gear train, the final error found may not appear to be of a regular periodic nature.

Other possible sources of periodic error are (a) an intrinsic error in the lead screw itself; (b) the lead screw not revolving truly about its axis; (c) errors in the abutment faces of the lead screw, and (d) axial float in the headstock spindle of the lathe [44].

3-6 Nomenclature and specification.

BS 2517: Definitions for use in mechanical engineering gives the standard definitions applicable to threads [9]. Details of the principle thread forms are contained in :

BS 3643 : ISO Metric Threads [45].

BS 4827 : ISO Miniature Threads [46].

BS 4846 : ISO Trapezoidal Threads [47].

BS 21 : Pipe Threads for Tubes and Fittings [48].

BS 84 : Whitworth Form Threads [49].

BS 93 : British Association (BA) Threads [50].

There are two main classes of thread form, vee threads and square threads, [51] certain ideas about specification, and tolerancing of screw threads of vee form (with a few minor exception) are common to all above threads systems, these will be explained with special reference to ISO Metric threads [45].

Figure (3-22), shows elements of parallel screw threads

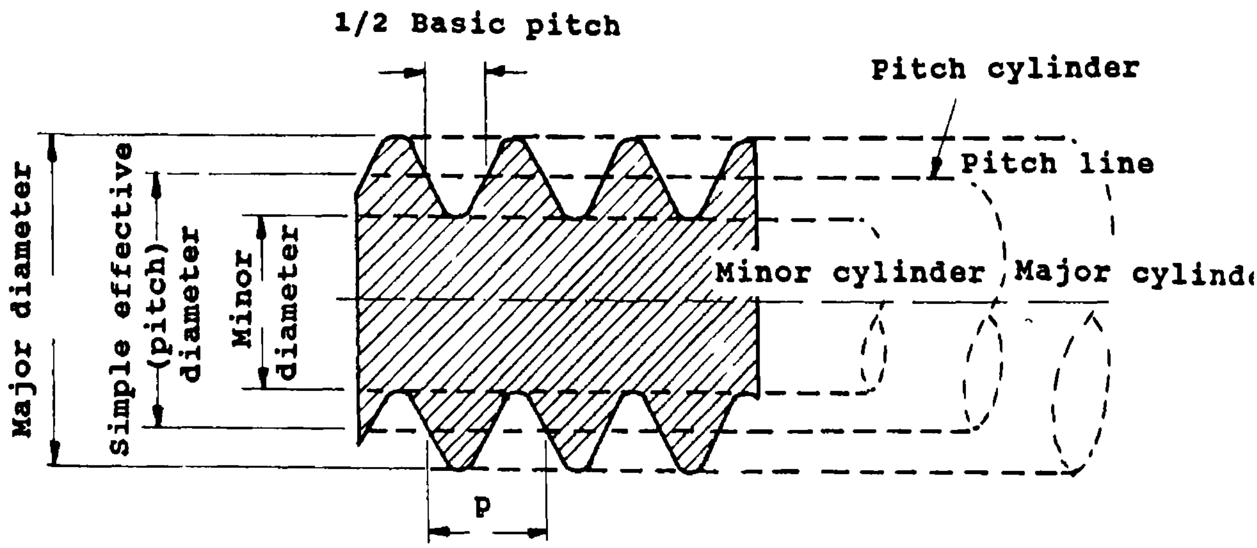


Figure (3-22)

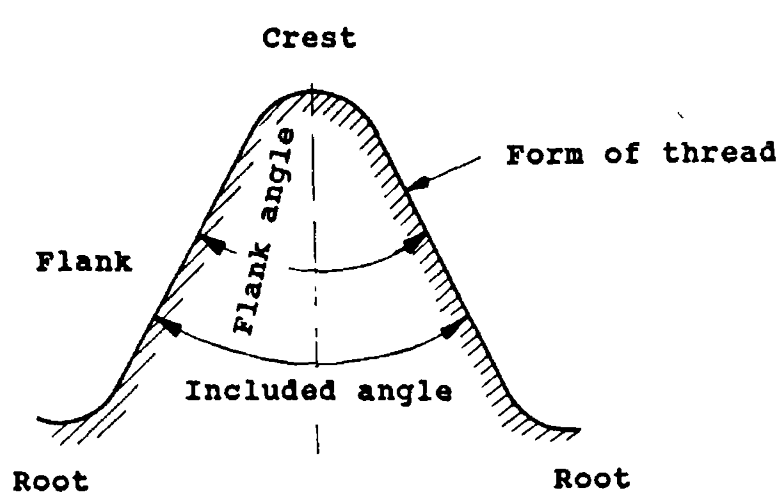


Figure (3-23)

of vee form, while figure (3-23), shows elements of form [44].

3-6-1 ISO metric screw threads.

The ISO basic profile for triangular screw threads is shown in figure (3-24). The design profile for ISO metric internal and external threads are shown in figure (3-25). These represent the profiles of the threads in their maximum metal condition. It will be noted that the root of each thread is deeper so as to clear the basic flat crest of the other thread.

The contact between the threads is thus confined to their stopping flanks. Basic numerical data for the various standard pitches of ISO metric threads is given in [52].

3-6-2 Basic Dimensions.

The basic dimensions of ISO metric screw threads refer to the basic profile, figure (3-26) shown these dimensions.

d = basic major of external thread (nominal diameter).

D_2 = basic pitch diameter of internal thread.

d_2 = basic pitch diameter of external thread.

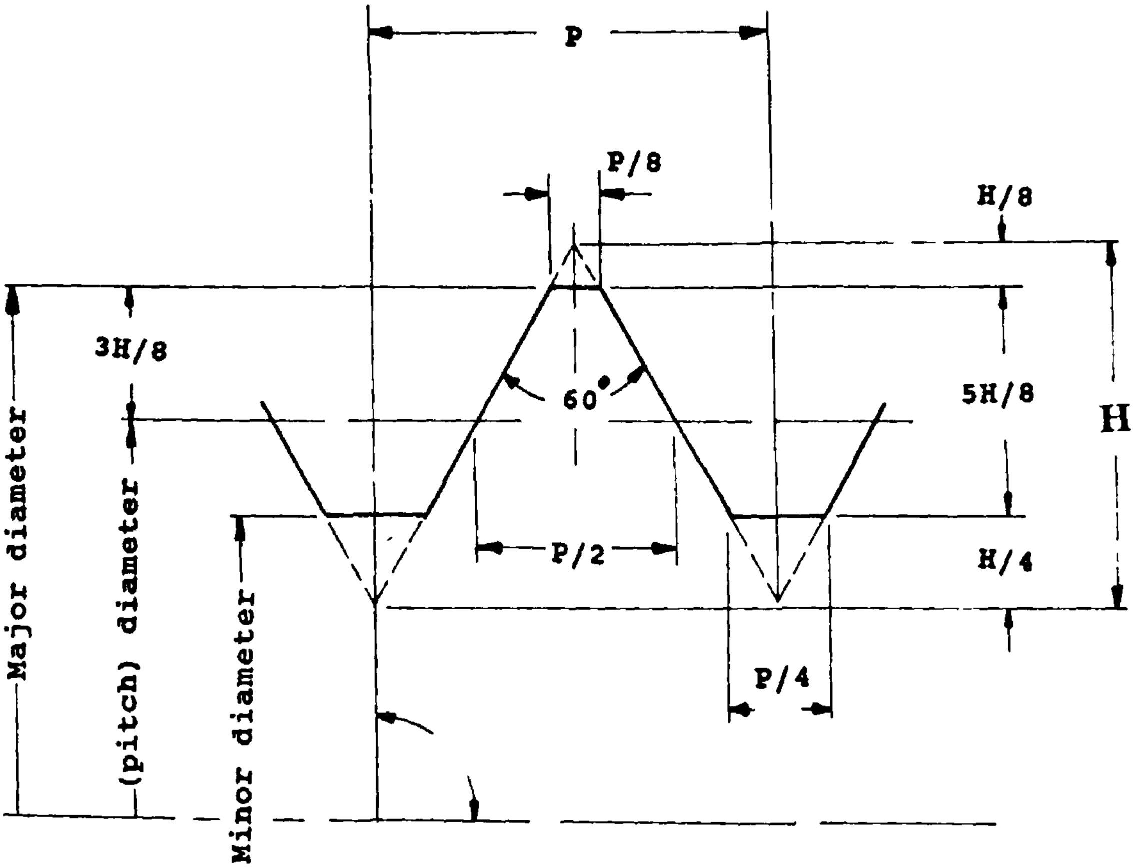
D_1 = basic minor diameter of internal thread.

d_1 = basic minor diameter of external thread.

H = height of fundamental triangle.

P = pitch.

The values of D2, d2, D1 and d1 have been calculated from



H= 0.86603 P   H/8 = 0.10825 P   3H/8 = 0.3247 P

H/4 = 0.21651 P   5H/8 = 0.54127 P

Figure (3-24)

Basic form of ISO metric thread

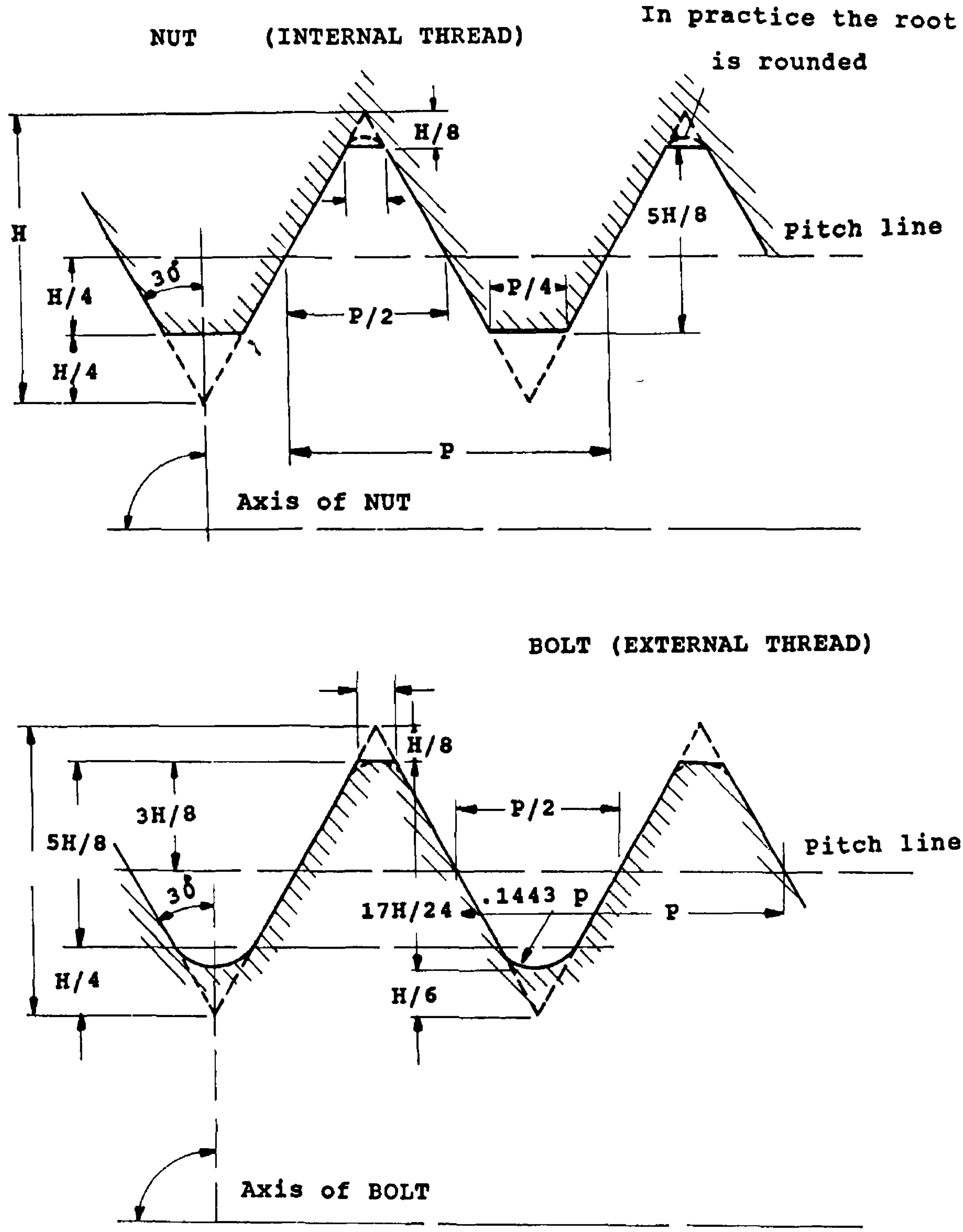


Figure (3-25)

Design form internal and external threads

(maximum metal condition)

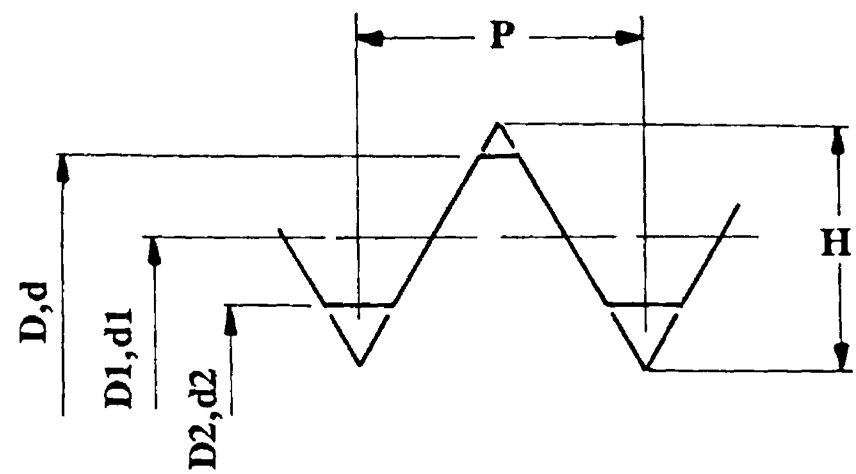


Figure (3-26)

the following formula and rounded, in the tables, to the third decimal place:

$$D_2 = D - 2 \times 3\,H/8 = D - 0.6495\,P$$

$$d_2 = d - 2 \times 3\,H/8 = d - 0.6495\,p$$

$$D_1 = D - 2 \times 5\,H/8 = D - 1.0825\,P$$

$$d_1 = d - 2 \times 5\,H/8 = d - 1.0825\,p$$

Dimensions of thread form elements [53], are :

$$H = \sqrt{3/2}\,P = 0.866\;025\;404\,p$$

$$5\,H/8 = 0.541\;265\;877\,p$$

$$3\,H/8 = 0.324\;759\;526\,p$$

$$H/4 = 0.216\;506\;351\,p$$

$$H/8 = 0.108\;253\;175\,p$$

3-6-3- Tolerance zone and class of fit.

A tolerance zone must be specified both in magnitude and position in relation to the basic size of the fit of which it is a part. The nature of a fit is dependent on both the magnitudes of the tolerances and the positions of the tolerance zone for the two member.
The position of a tolerance zone is defined by the distance between the basic size and the nearest end of the tolerance zone.
This distance is known as the " fundamental deviation ".
In the ISO metric screw thread system fundamental deviations are designated by letters. Capitals for internal threads and small letters for external threads.
The magnitudes of tolerance zones are designated by tolerance grades (figures).

A combination of a tolerance grade (figure) and a fundamental deviation (letter) forms a tolerance class designation, e.g 6g:

In BS 3643 " class of fit " indicates the degree of fit between external (bolt) threads and internal (nut) threads.

ISO definitions designate this condition as tolerance quality, but to maintain conformity with British practice the designation " class of fit " is preferred. Thus, " fine tolerance quality " conforms to the " close " class of fit and "coarse tolerance quality" conforms to the " free " class of fit. The " medium " designation is common to both methods.

The complete ISO metric screw thread tolerancing system provides many combinations of tolerance grade and fundamental deviations to cater for most application ; table (3-2) gives, classes of fit for ISO metric screw threads [52].

Also figure (3-27) illustrates tolerance zones for the close fit (5H/4h). From the tolerance zones shown in figure (3-27) it follows that three different types of error are allowed:

(a)- Error of the flank angle.

(b)- Error of pitch over the length of fitting.

(c)- Error of effective diameter [9].

3-6-4- Application of fit.

" **Medium fit** ", (6H/6g). The " medium " class of fit is appropriate for most general engineering purposes. The minimum clearance associated with the fit associated in free assembly, and this minimizes galling and sizing in high speed assembly.

" close fit ", (5H/4h). The " close " class of is applied to threads requiring a closer fit than that normally obtained with the " medium " class of fit and fit and should only be when close accuracy of thread form and pitch is particularly required.

Consistent production of threads of this fit demands the use of high quality production equipment and particularly through inspection.

" free fit ", (7H/8g), the " free " close of fit is primarily intended for applications in which quick and easy assembly is needed even when the threads have become dirty and/or slightly damaged.

Figure (3-28) shows the relationship between tolerance zones and classes of fit [52].

3-6-5- Designation.

The complete designation for a screw thread comprises a designation for the thread system and size, and a designation for the thread tolerance class.

A screw thread designates by the letter M followed by the values of nominal diameter and of the pitch, expressed in millimetres and separated by the sign x. For example:

M6 x 0.75

The absence of the indication of pitch means that a

Table (3-2)

Class of fit	Tolerance class	
	Internal threads (nuts)	External threads (bolts)
' Close '	5H	4h
' Medium '	6H	6g
' Free '	7H	8g

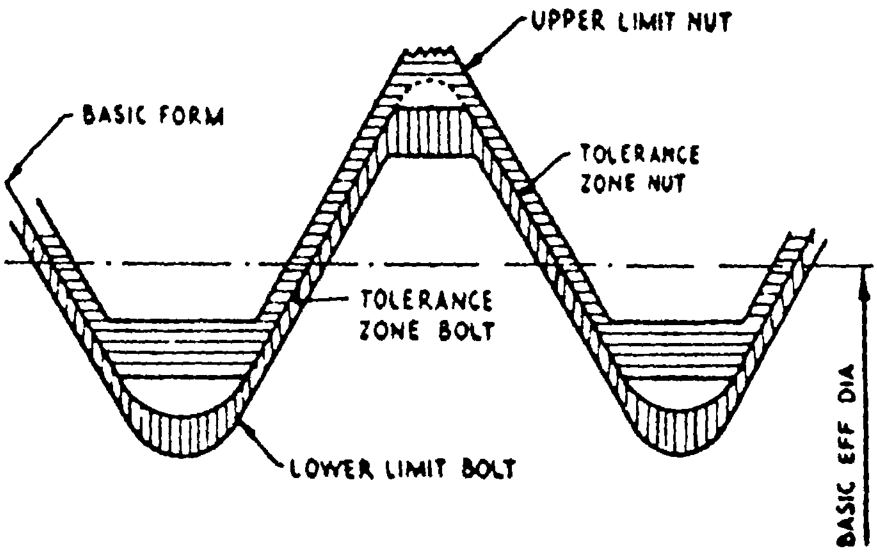
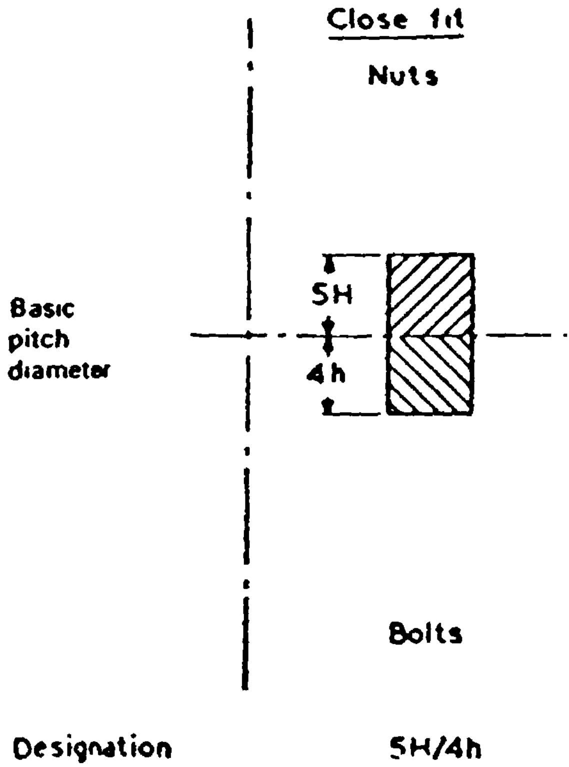


**Figure (3-27)
Tolerance zones for close
fit (5H/4h)**


Close fit
Nuts
Basic pitch diameter
5H
4h
Bolts
Designation
5H/4h

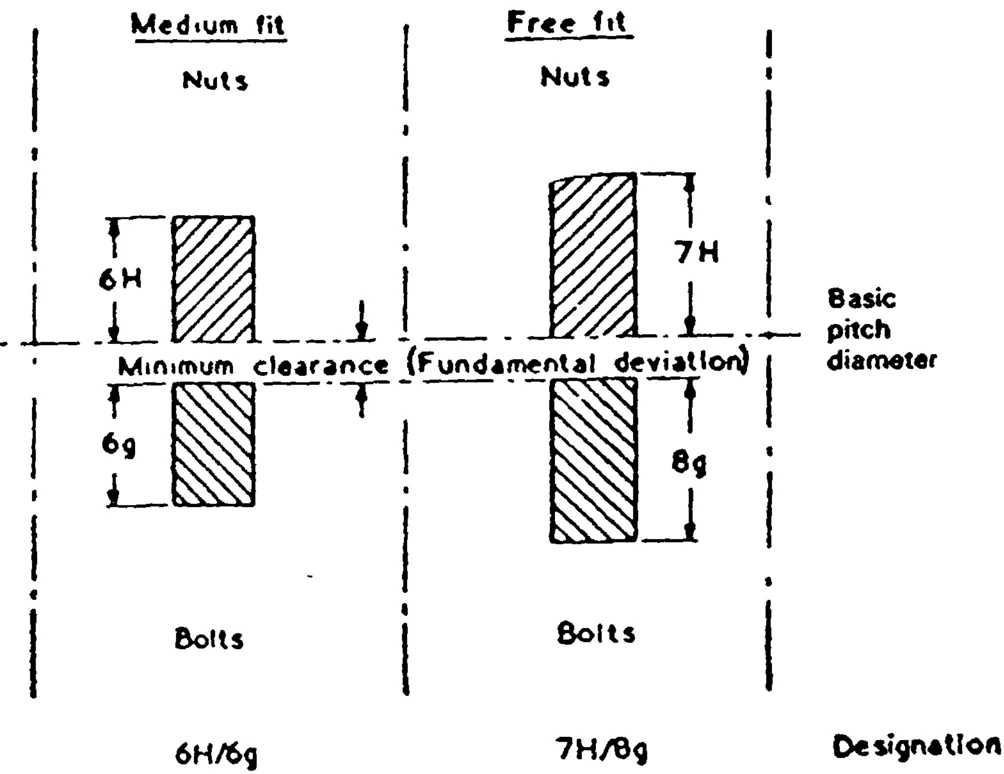

Medium fit
Free fit
Nuts
Nuts
6H
7H
Basic
pitch
diameter
Minimum clearance (Fundamental deviation)
6g
8g
Bolts
Bolts
6H/6g
7H/8g
Designation

Figure (3-28)

coarse pitch is specified. For example M6 the tolerance class designation comprises class designation for the pitch diameter tolerance followed by a class designation for the crest diameter tolerance. Each class designation consists of:

(1)- A figure indicating the tolerance grade.

(2)- A letter indicating the tolerance position, Capital for nuts, small for bolts.

If the two class designations for a thread are the same it is not necessary to repeat the symbols , [53].

3-7 Inspection of screw thread.

The inspection of screw threads may be by gauging or measuring.

3-7-1 Inspection by gauging.

BS 919 " screw gauge limits and tolerances ", part three "Gauges for ISO metric screw threads " contains the recommended gauging system for checking threads of nominal diameter 1mm and larger which have been accordance with BS 3643 " ISO metric screw threads ".

provision is made for the following types of gauges:

(a)- Screw gauges.

(b)- plain gauges (for the crest diameters).

(c)- Setting plugs, in both single and double length.

(d)- Check plugs.

(e)- Wear check plugs.

Information is given about the function and methods of use of the various types of gauges and a recommended procedure is given for the settlement of disputes which may arise when boardline products are inspected.

3-7-2 Inspection by measurement.

Measurement of a screw threads can be very complex; there being a number of elements to be measured, some of which are interrelated. Of the elements, the following will normally be measured:

(a)- Major Diameter.

(b)- Minor Diameter.

(C)- Form, particularly flank angles.

(d)- Pitch.

(e)- Pitch diameter.

the measurement of the flank angles is the most important measurement of thread form which, on very large screw threads, may be made by contact methods [54].

Full information on the measuring of screw threads will be found in the NPL booklet. Notes on Applied science, NO.1: Gauging and measuring screw threads [44].

Also, Information concern automated thread measurement, using different methods and techniques, for the last decade, can be found in chapter two.

CHAPTER FOUR

4-DEVELOPMENT OF THE MEASURING RIG.

The oldest of the physical sciences is the study of the motion of the objects.

Kinematics: Is that part of mechanics [55], which deal with motions of bodies without regard to the force responsible of the motions .

Displacement: Is the vector quantity arises in the study of kinematics, [56], which may be defined as a change of position of a particle [55].

4-1 Definitions.

1- ACCURACY OR CORRECTNESS :

This may be defined as the amount of correction which must be made to the instrument readings in respect of the values of the quantities being measured, [54], also it may be defined as conformity with or nearness to the true value of the quantity being measured [57].

2- POINT OF ACCURACY :

Here the accuracy of an instrument is stated for only one or more points in its range [57].

3- PERCENTAGE OF TRUE VALUE :

If the accuracy of an instrument is expressed in this way, then the error is calculated thus:

$$\textbf{Error} = \{ (M_v - T_v) / T_v \} \times \%100 \qquad (4\text{-}1).$$

The percentage error stated is the maximum for any point in range of the instrument, [57].

4- PERCENTAGE OF FULL-SCALE DEFLECTION PERCENTAGE (f.s.d)

Here the error is calculated on the basis of the maximum value of the scale, thus [57] :

$$\textbf{Error} = \{ (M_v - T_v) / M_s \} \times 100\% \qquad (4\text{-}2).$$

5- PERCISION OR REPEATABILITY :

This is the repeatability of the reading taken of the same value by the same instrument [57].

6- SENSITIVITY AND RANGE :

This may be defined as the rate of displacement of the indicating device of an instrument, with respect to the measured quantity. See figure (4-1), [54].

The sensitivity is taken to mean the relation between the input signal to an instrument or a part of an instrument system and the output, i.e.

$$\text{Sen} = (\text{C.O.S})/(\text{C.I.S}) \qquad (4\text{-}3).$$

The sensitivity will therefore be a constant in a linear instrument or element.

7- ENVIRONMENT :

The partical condition in which an instrument has to operate may affect, its accuracy, precision, and reliability.

8- LINEARITY :

Is defined as the ability to reproduce the input characteristically, and this can be expressed by the equation:

$$Y = m x + c \qquad (4\text{-}4).$$

9- RELIABILITY :

The reliability of a system is as defined as the probability that it will perform it assigned functions for a specific period of time under given condition.

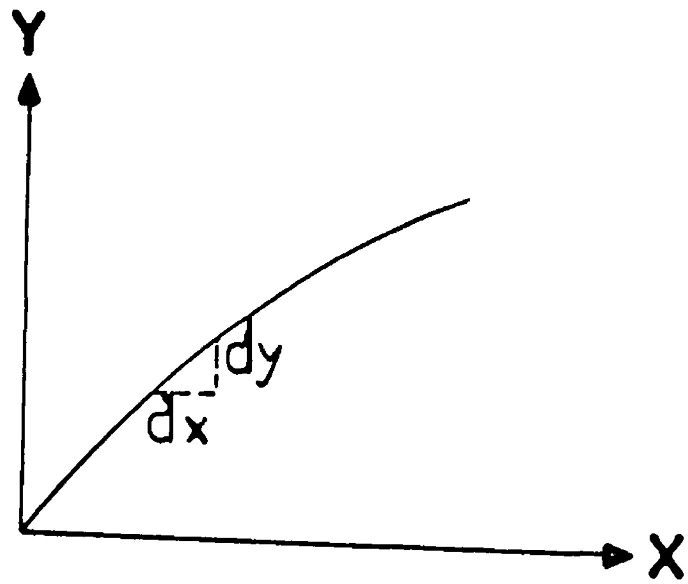


Figure (4-1)

10- MAINTAINABILITY :

The maintainability of a system is the probability that in the event of failure of the system, maintenance action under given conditions will restore the system within a specified time.

11- CALIBRATION :

It is an essential part of industrial measurement and control. It can be defined as the comparison of specific values of the input and output of an instrument with a corresponding reference standard [54].

12- STYLUS :

The stylus is that part of the measuring system which makes contact with the component causing the probe to produce a trigger signal. The type and size of stylus used is dictated by the feature to be inspected. In all cases, maximum rigidity and sphericity of the stylus are vital [58].

4-2 Principles of design

4-2-1 Kinematics principles

Measuring instruments and machines, incorporate, in their important features, principles, which are based on kinematics. It will be seen that, in general the motions which must be considered in the design of a measuring machines are those of straight line and rotary motion. Design experience over many years has shown that kinematic principles must be closely followed, in order that machines and instruments should possess the following characteristics:

(a)- A high degree of sensitivity.

(b)- A high degree of accuracy.

(c)- Freedom from variance.

(d)- minimum inertia in the moving parts of the indicating mechanism.

All instruments which depend wholly or in part on a linkage or other mechanical system or on the displacement of a fluid, for their operation are subject to the disadvantage of inertia.

Inertia produces a condition referred to as passivity or sluggishness. It may be determined for any given instrument by noting the smallest range in the measured quantity which produces any change in the instrument reading. Passivity is closely associated with sensitivity: passivity may only show itself as a change in the sensitivity of an instrument at a particular point in its scale reading the measuring machine in addition to instruments, also possess the foregoing characteristics, and that in each case they may be reduced to acceptable limits by the application of kinematic principles. In fact only by strict observance of them can the functional requirements of a design be satisfied.

Commonly, in measuring instruments and machines, it is necessary to allow one degree of freedom of a member, which require five constraints, or to completely constant a member, thus constituting a fixture.

Only by the application of kinematic principles can the design of an instrument or machine be such that its accuracy in operation does rest entirely on its accuracy of manufacture.

Not only do kinematic principles allows simplicity of manufacture, but they provide for adjustment at instrument assembly and testing stage, so that completely satisfactory operating characteristics may be achieved .

4-2-2 Basic characteristic of measuring devices.

The function of a measuring device is to sense or detect a parameter encountered in an industrial process or in scientific research, such as a pressure, temperature, flow, motion, resistance, voltage, current and power.

The measuring device must be capable of faithfully and accurately detecting any changes that occur in the measured parameter. For control purpose, the measuring instrument either generates a warning signal to indicate the need for a manual change or activates a control device automatically. For obtaining optimum performance, a number of basic characteristics are to be considered. These characteristics are as follows: ***Accuracy,***

precision, error, linearity, hysteresis, resolution and scale readability, threshold, reliability and maintainability, span, and dynamic accuracy.

The accuracy of a complete system is dependent upon the individual accuracies of the primary sensing element, secondary element, and the manipulating devices. Each unit contributes to the accuracy with separate limits specified. If $(+/- \ a_1)$, $(+/-a_2)$ and $(+/-a_3)$ are the accuracy limits of a typical system, and A is the overall accuracy, the lowest limit of accuracy can be expressed as:

$$A = +/- \ (a_1 + a_2 + a_3) \qquad (4\text{-}5).$$

and the root mean square is often specified, since it is not probable that all the units of the system will have the greatest static error at the same point and at the same time.

In actual measurement the effect of the different errors on the transducer behaviour should be clearly known.

The knowledge of these individual errors, can be often used to correct the final data and thereby increase the overall accuracy of the measurement.

The error observed when the instrument is under the reference condition is termed as the intrinsic error. The absolute error is the difference obtained by subtracting the true value of a quantity from the observed value. The relative error is the ratio of the absolute error to the true value.

In certain cases, it may be necessary to express this as relative linearity error k which can be written as:

$$k = (k_a - k_b) / k_a \qquad (4\text{-}6).$$

The statistical errors in a measurement can be considered in terms of the statistical mean and the standard deviation. If x_1, x_2,....x_2 represent a set of measured values of a quantity, the statistical mean $\bar{x}$ of these readings is given by:

$$\bar{x} = 1/n \sum_{i=1}^{n} x_i \qquad (4\text{-}7).$$

The standard deviation, indicating the degree of dispersion of readings about a mean value, can be expressed as:

$$\sigma = \sqrt{1/n \sum_{i=1}^{n} d_i^{\,2}} \qquad (4\text{-}8).$$

If the measurement system is subjected to rapidly varying inputs, the relation between the input and output becomes different from that of the static or quasistatic case.

The dynamic response of the system can be expressed by means of a differential equation. If this is a linear differential equation, the system is dynamically linear. The basic dynamic characteristics depend on the order of differential equation of the system [59].

4-2-3 Intelligent instrumentation:

Intelligent instrument is a term, which has come to mean: the use of measurement system to evaluate a physical variable employing usually a digital computer to perform all (or nearly all) the signal/ information processing.

It is one where after a measurement has been made of a variable some further processing (analogue or digital) is carried out to refine the data, for presentation to an observer or other computers.

Intelligent instrumentation involves the development of systems to process information and signals. Thus the concepts of systems engineering can be applied. The signal is connected to a processing system which would probably include some or all of the following elements: sampler, analogue to digital converter, interface to digital computer, software routine and software output driver.

To achieve the good design of system in intelligent instrumentation a style of engineering is adopted which utilities computer systems, control systems and digital electronics in various mixes, [60].

4-3 Design and development of an automatic inspection system.

In general, kinematics principles, basic characteristics of measuring device, and the concepts of an intelligent instrumentation are adopted with other considerations to design and arrange the different elements of our automatic measuring system.

Lever, clamping and rotating, and sliding mechanisms, which are driven and controlled by a personal computer, are refered to as the mechanical design.

While, motors and the linear variable differential transformer (LVDT), where their signals are interfaced and processed using a special arrangements, are refered to as the electric design.

Figure (4-2), shows the main elements of the adopted design, which are included under the following:

(1)- Mechanical design.

(2)- Electronic design.

Also special software was prepared to drive, control and process the different Input/Output signals.

4-3-1 Mechanical design.

A certain information and data, relating designing factors and other considerations, such as frictional force and moment of inertia were considered and calculated to find out the different characteristic specification of our mechanical elements.

Frictional force opposes movement regardless of direction, where, moment of inertia is an indication of resistance to change in speed. Thus, shapes and weights of the different moving elements were carefully calculated, because, moment of inertia depends on shape

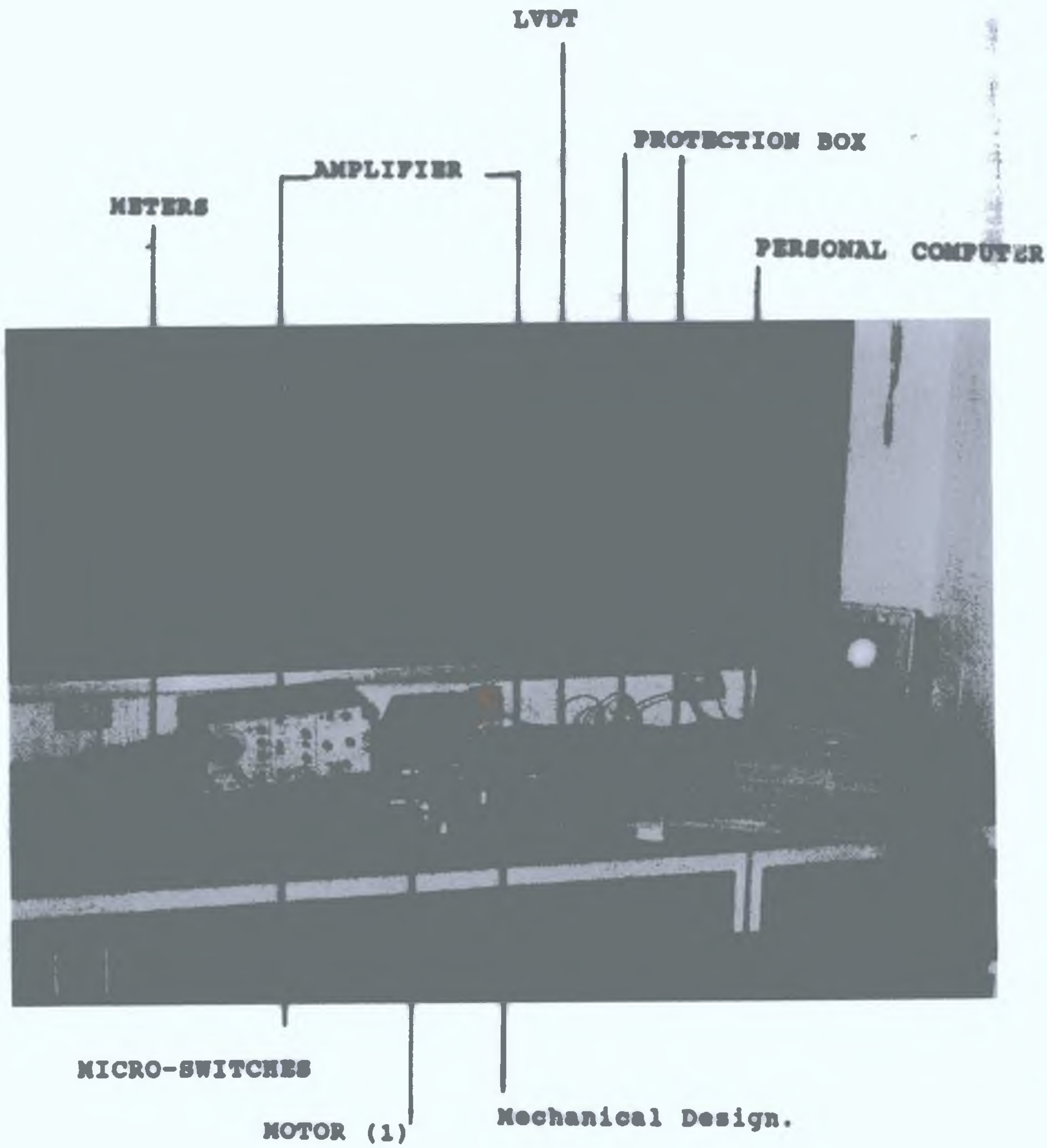

LVDT
PROTECTION BOX
AMPLIFIER
METERS
PERSONAL COMPUTER
MICRO-SWITCHES
MOTOR (1)
Mechanical Design.

Figure (4-2)

as well as weight, also low frictional forces have been achieved by using linear ball bushings and ball screw The following mechanisms represent our mechanical design:

(1)- Lever mechanism

(2)- Clamping and rotating mechanism

(3)- Sliding mechanism.

4-3-1-1 Lever mechanism.

The lever, is one of two simple mechanical magnifying elements Figure (4-3), shows, that the mechanism consists of a stylus which represent the first sensing element in our measuring system Different types of stylus may be fixed on the specified hole on one side of the stylus arm, while, an electrical sensing element makes the required contact at a specified point on the other side of the stylus arm

Pivot holds the stylus arm to the lever body which may be adjusted to any height on the shaft using a special bolt The shaft is fixed tightly to the lever base The stylus arm has one degree of freedom (pivot on point)

Pivot and stylus tip control the sensitivity of this mechanism, therefore a suitable tolerances were adopted to fit the required accuracy

If a stylus is dragged along the surface, its motion traces out the profile of the surface thus, required rotating on pivot point is generated by the object under test causing a certain displacement to the stylus The

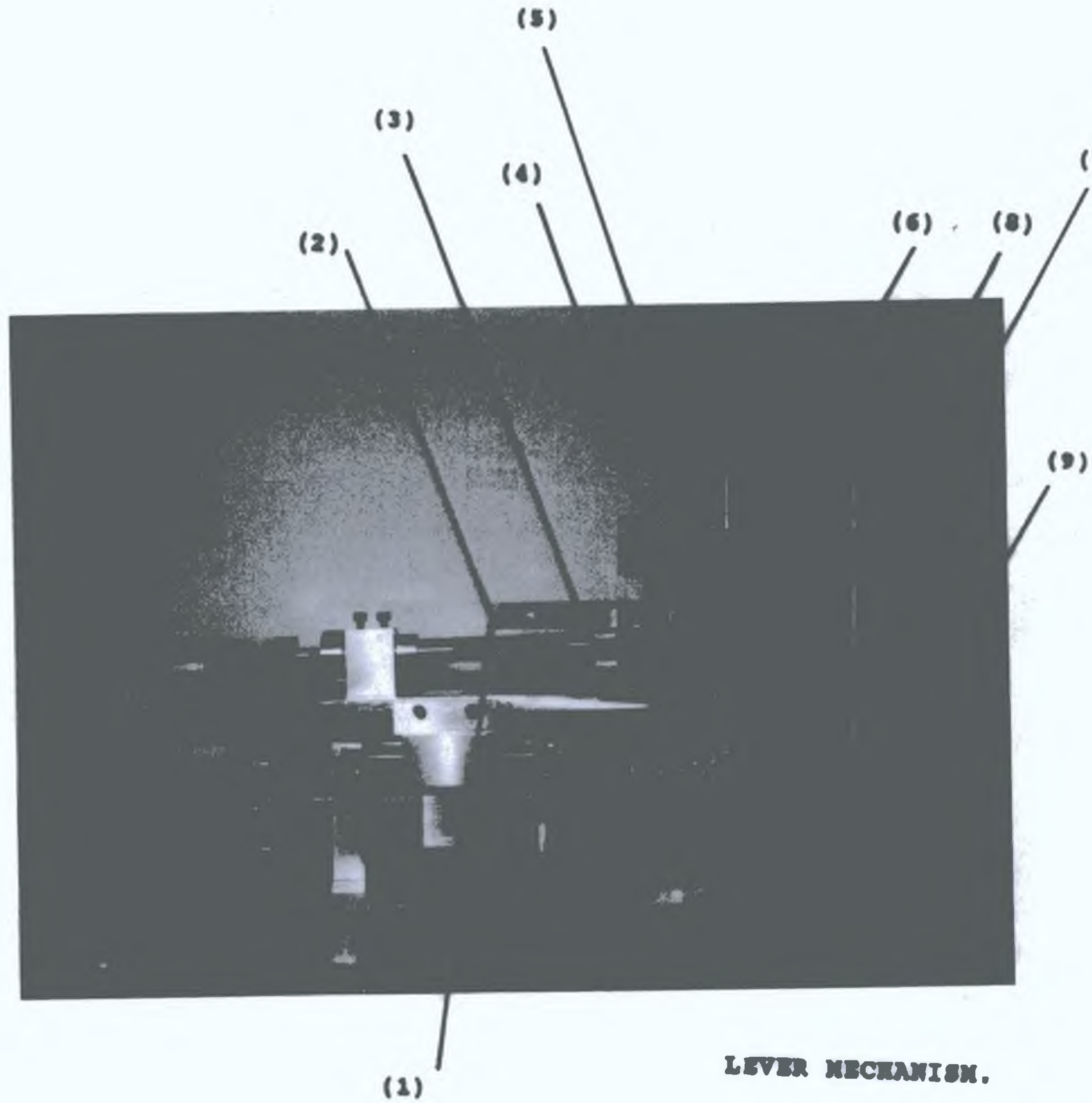


Figure (4-3)

LEVER MECHANISM.

(1)..........STYLUS

(2)..........STYLUS BOLT

(3)..........LEVER ARM

(4)..........PIVOT

(5)..........LEVER BODY

(6).........(LVDT) BOLT

(7)..........ADJUSTING BOLT

(8)..........SHAFT

(9)..........BASE

difference between two heights is amplified by the lever which converted on the other side into electrical signal The stylus arm and the lever body are made of aluminum H30, pivot material is phosphor bronze The stylus used for the simulation tests was made of silver steel
The stylus arm, lever body, pivot and the previous stylus were manufactured at the workshop of the school of mechanical and manufacturing engineering
While the stylus, *SP75, SP36R and SP20R,* were purchased from (Inspection Equipment Co.Ltd unit 37, Western Parkway Business Centre, Ballymount Road, Dublin 12)
The shaft, bolts and lever base were ready at the workshop

4-3-1-2 Clamping and rotating mechanism

The Clamping and rotating mechanism provides the object under test the required support, and the desired form of motion It consists of four separate sets, which are fixed to a solid base
Figure (4-4), illustrates these sets, which are as follows

(1)- Support jaw

(2)- Vee block

(3)- Movable jaw

(4)- Motor set and base

(1)- Support jaw

Sliding mechanism

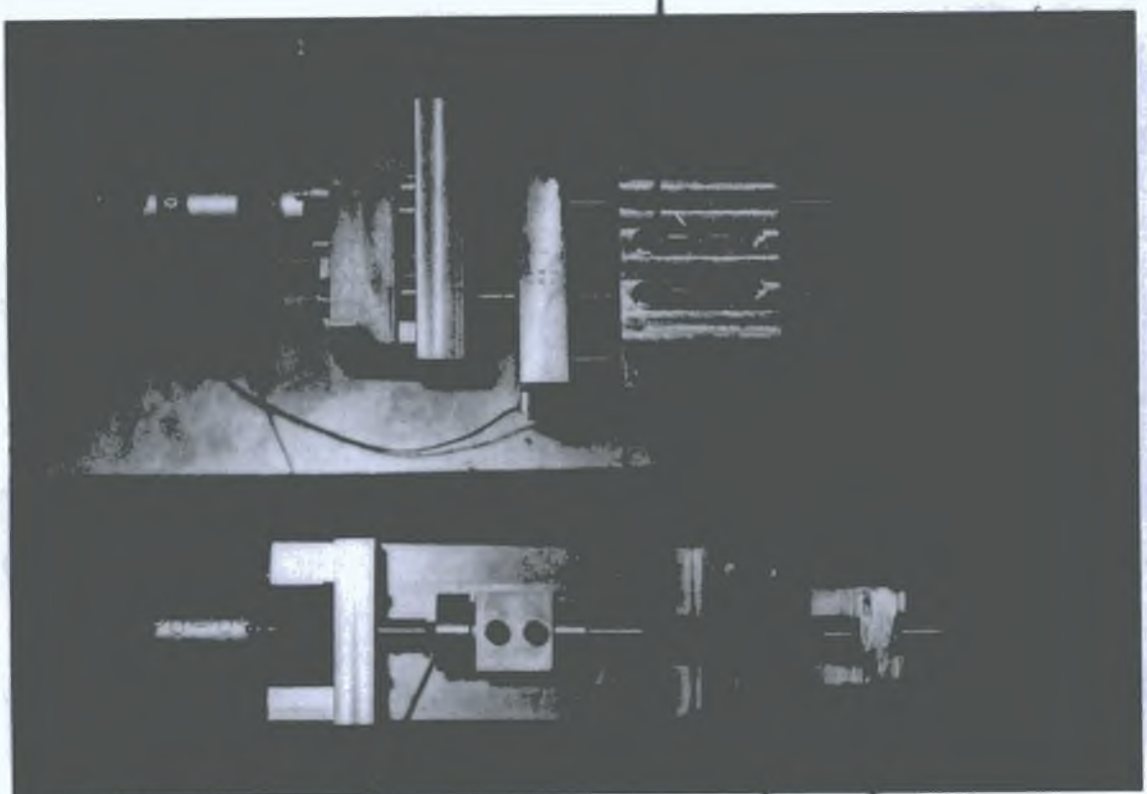

3- Movable jaw.
1- support jaw.
4- Motor set and base.
2- Vee block.

Figure (4-4)

This set provides the object under test, the required side supporting during various steps of the operational cycle

It consists of a base made of Aluminum H30, and has one degree of freedom which may be used for calibration task before starting the cycle Thrust bearings , shaft , and changeable jaw with special bolt.

The jaw has one degree of freedom and its martial is silver steel, like the shaft which also has one degree of freedom Figure (4-5)

The base, jaw and shaft were manufactured at the workshop of the school, while the thrust bearings were purchased from, (FAG Ireland limited, Greenhill industrial Eastate, Walkinstown, Dublin 12)

(2)- Vee block

In order to increase the flexbility of the system , vee block were designed to fit different sizes of the cylindrical objects

Figure (4-6), illustrates the different parts, which are, the vee block body, cylindrical guidance, holding bolt, and adjusting element

The fine thread which represents the adjusting element in our design, controls the vertical position of the object under test to the correct height, it has a very small increment, which generates as soon as rotating it.

Therefore, micrometer can be replaced instead of it , to achieve further degree of accuracy, and to make the calibration task, more easy, quick, and perfect

Strongly, we recommend, that calibration should be performed once for each type of inspection, also, holding bolt should not be allowed to move after calibration, thus errors due to this calibration will not take place

The fine thread and cylindrical guidance are made of silver steel, and The vee block and holding bolt are made of Aluminum H30. All parts were manufactured in the workshop of the school

*(3)- **Movable jaw***

The set provides the object under test with the three following motions

(a)- Clamping the object

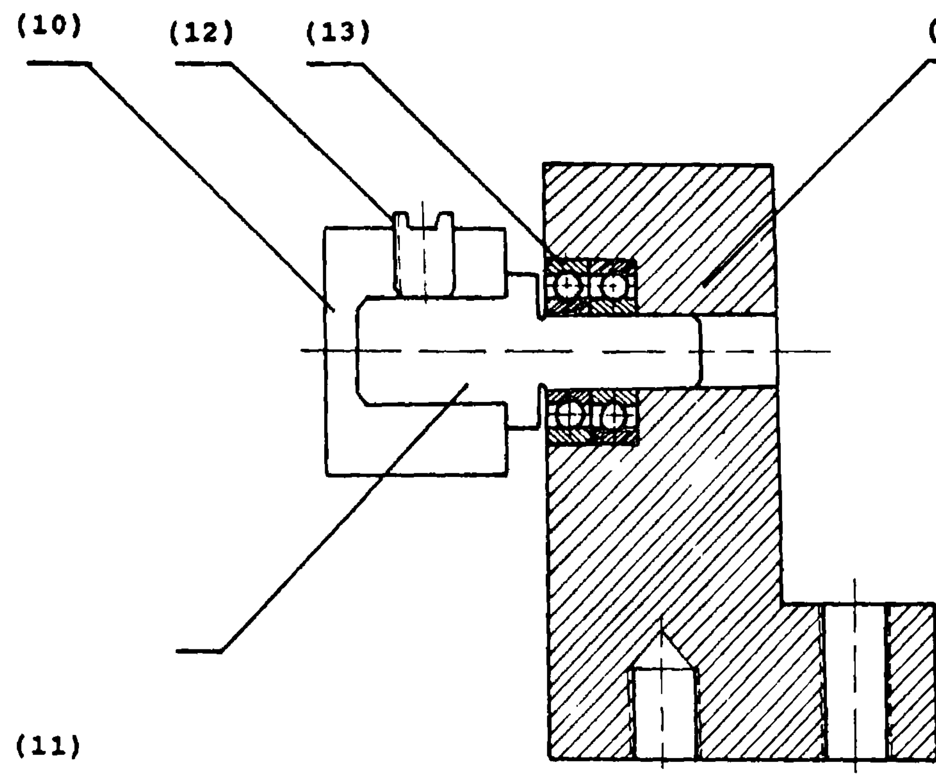
(b)- Provide the object the rotating motion to accomplish the helix inspection step

(c)- Releasing the object at the end of the test

A special design, has a simple feature adopted in order to achieve the previous motions

The design consists of, a clamping jaw which has two degrees of freedom, fixed cylinder has an internal guidance, cover, thrust bearings, clip-rings, lead screw, spring and housing body see figure (4-7)

The Clamping jaw, and the lead screw are made of silver steel, Cover, fixed cylinder, and housing body are made of Aluminum H30



SUPPORT JAW

(10).........JAW

(11).........SHAFT

(12)..........BOLT

(13).........BEARING

(14).........BODY

Figure (4-5)

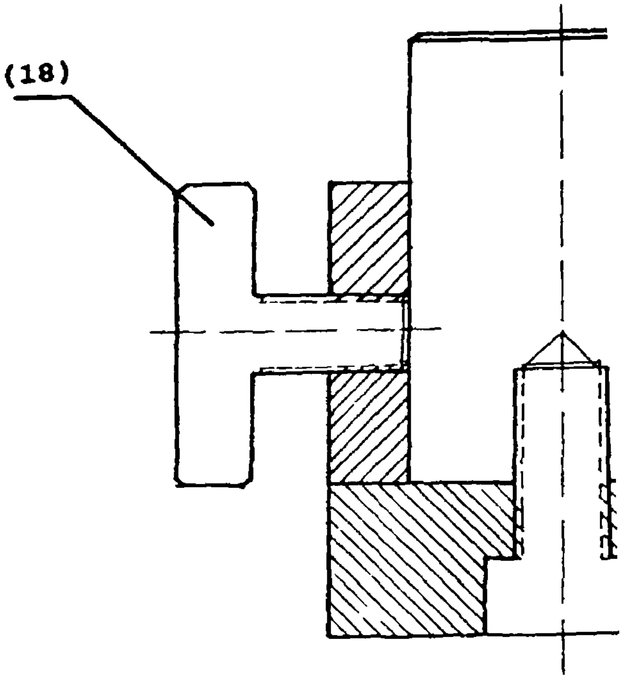
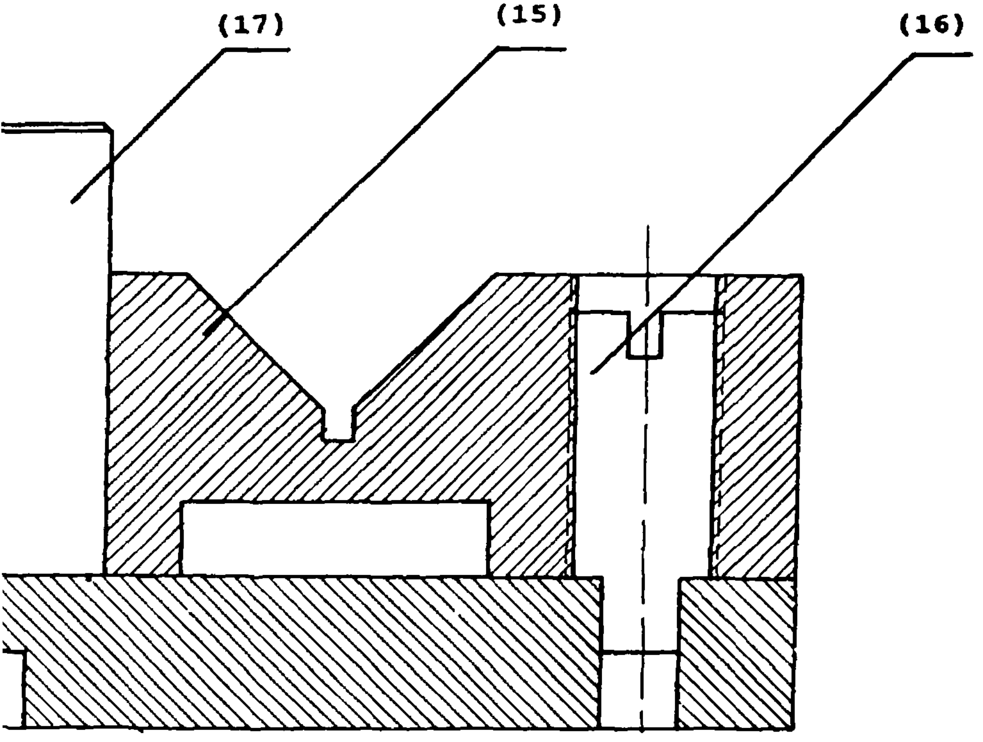


Figure (4-6)



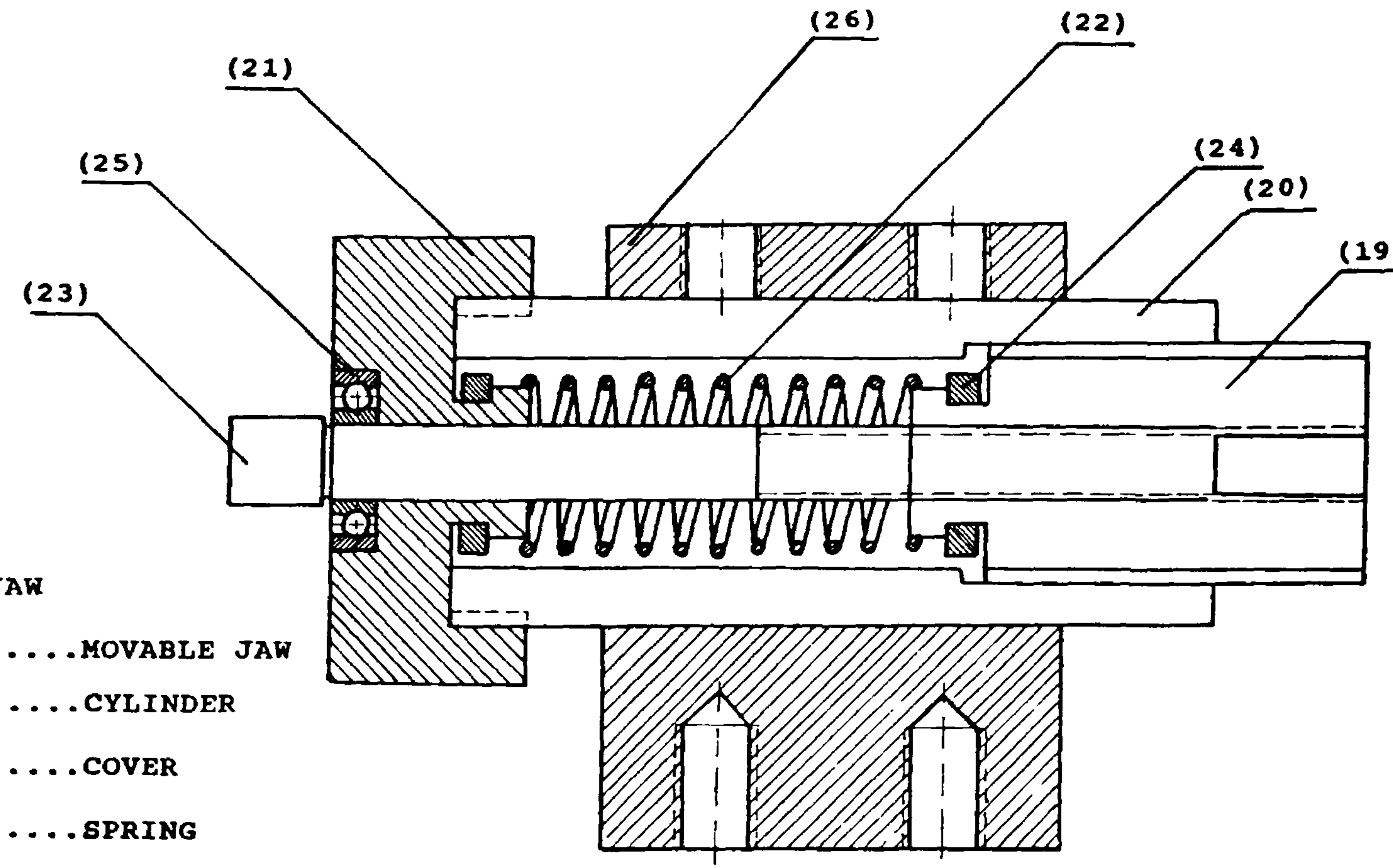
VEE BLOCK

(15)........VEE BODY

(16)........FINE THREAD

(17)........GUIDANCE

(18)........ADJUSTING BOLT



MOVABLE JAW

(19).........MOVABLE JAW

(20).........CYLINDER

(21).........COVER

(22).........SPRING

(23)........LEAD SCREW

(24)........CLAP RING

(25)........BEARINGS

(26).......HOUSING BODY

Figure (4-7)

The spring material is stainless steel All previous parts were manufactured at the workshop of the school, except the spring, and the clip-ring the thrust bearings were purchased from FAG Ireland .

(4)- motor set and base

Figure (4-8), shows that, this set consists of a mass made of Aluminum H30 And the general base which is made of the same martial

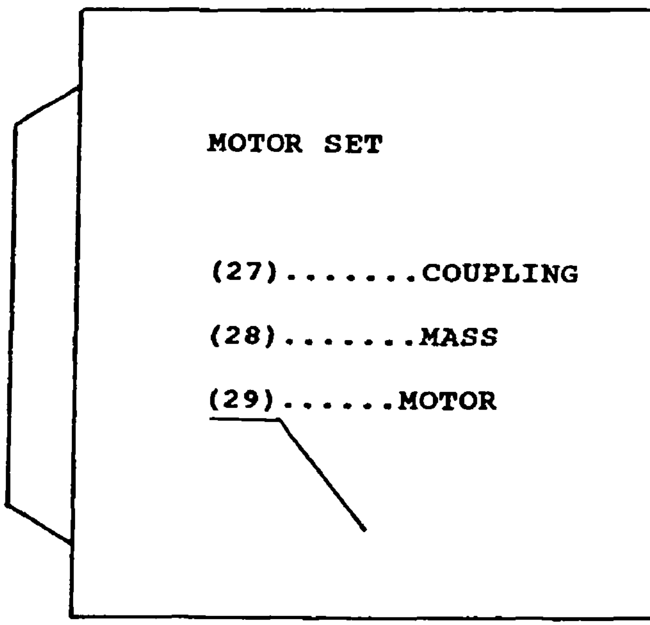
These two parts, also were manufactured at the workshop of the school

4-3-2-3 Sliding mechanism

A linear movement, with a constant velocity should be provided to the object under test in order to perform the form inspection

The sliding mechanism was designed to provide this movement It consists of a carriage with a rolled thread ball screw and a single nut with flank " reference No 1532-4-6003, lead deviation dP_{300} = 50 micron " , four ball bushings with self-Alignment feature, closed type " reference No 0670-210-40, h7/js7, weight 0.017 Kg, and carrying part

The support masses are fixed to the main base Two guidance shafts are fixed tightly to the support masses Finally a set of thrust bearings fixed inside the support masses


MOTOR SET
(27).......COUPLING
(28).......MASS
(29)......MOTOR

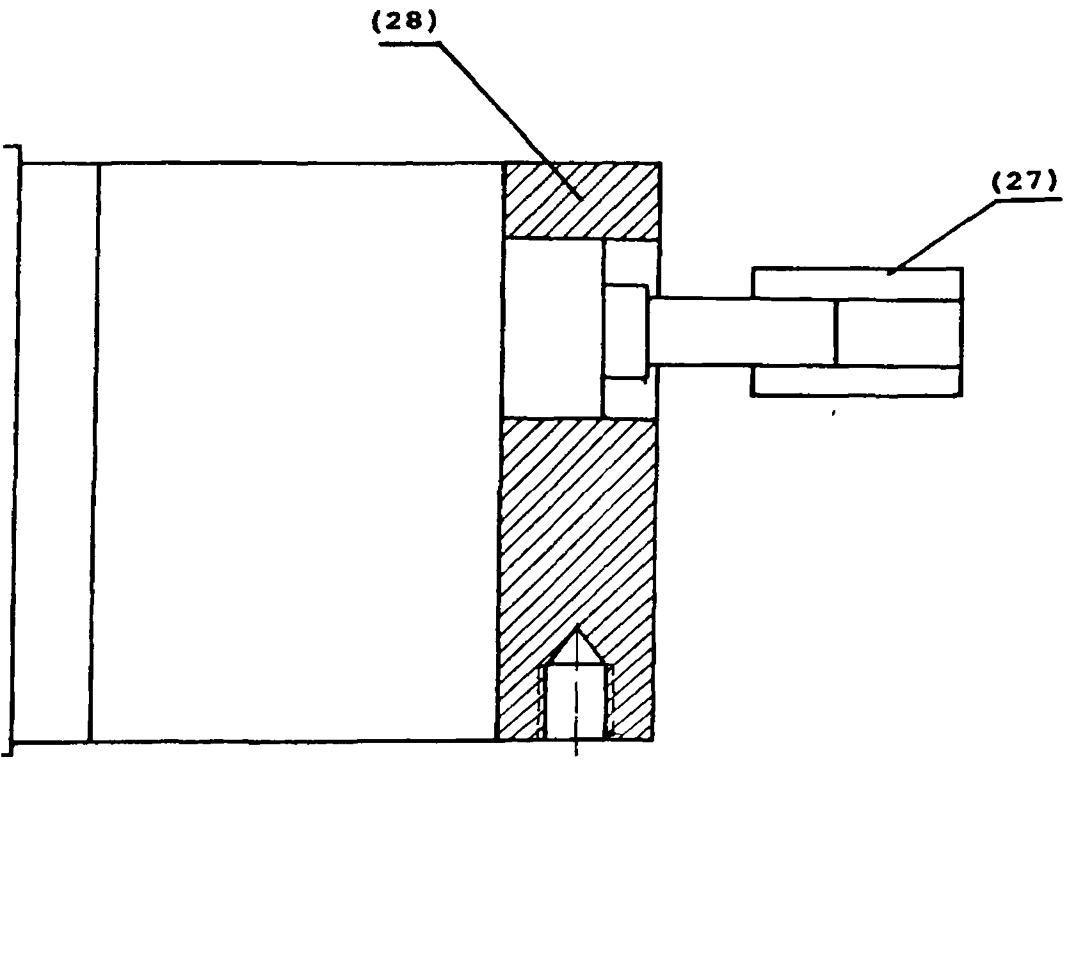
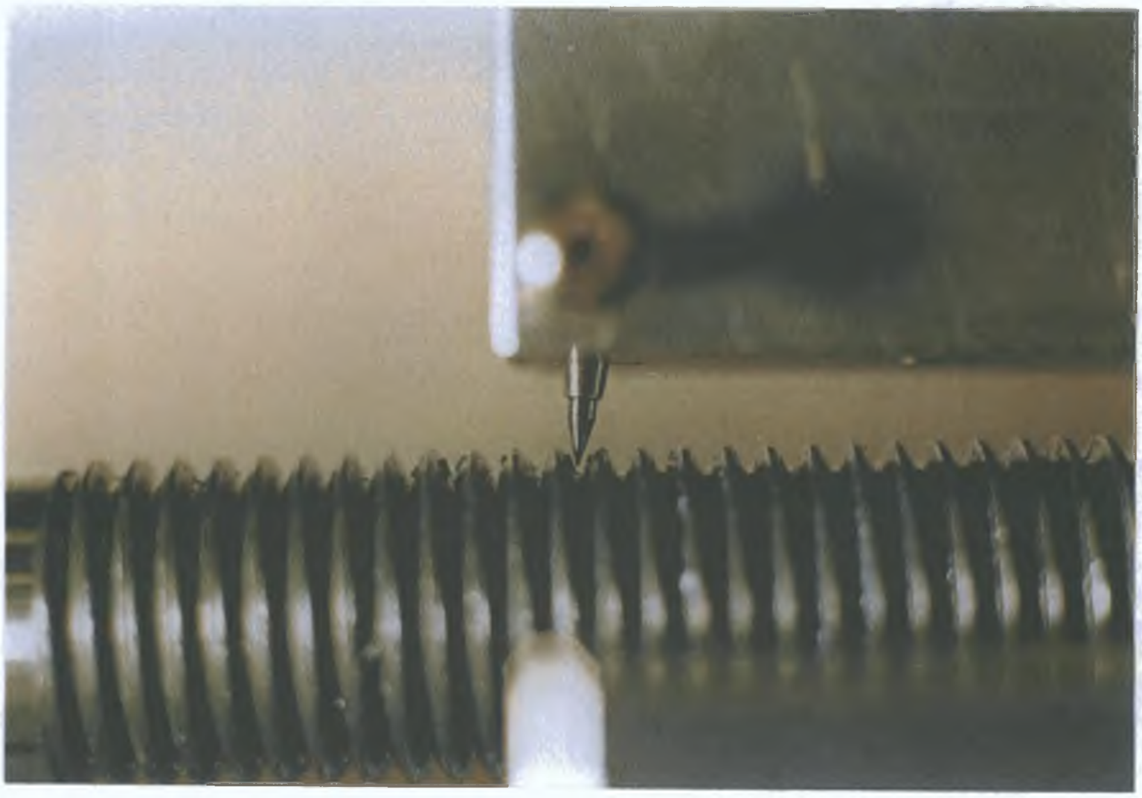


Figure (4-8)



The rolled thread ball screw is joined to the driving motor through coupling Figure (4-9), illustrates these parts

The design has one degree of freedom for the movable parts, sliding for the carriage , and rotating for the rolled thread ball screw and the thrust bearings

The carriage, carrying part, support masses and the main base are made of Aluminum H30 While coupling is made of silver steel These parts were manufactured at the workshop of the school

thrust bearings were purchased from FAG Ireland

The rolled thread ball screw ,single nut with flank, guidance shafts and the ball bushings were purchased from RHP bearings

It can be noticed that most of the parts were made of a light weight material in order to reduce the moment of inertia

Finally, the frictional forces were ignored, because of using the ball bushing, the rolled thread ball screw and single nut system

4-3-2 Electronic design

Two important tasks are required of our electronic elements, those are·

(1)- Driving the mechanical parts

(2)- Translate the stylus movements into a usable output

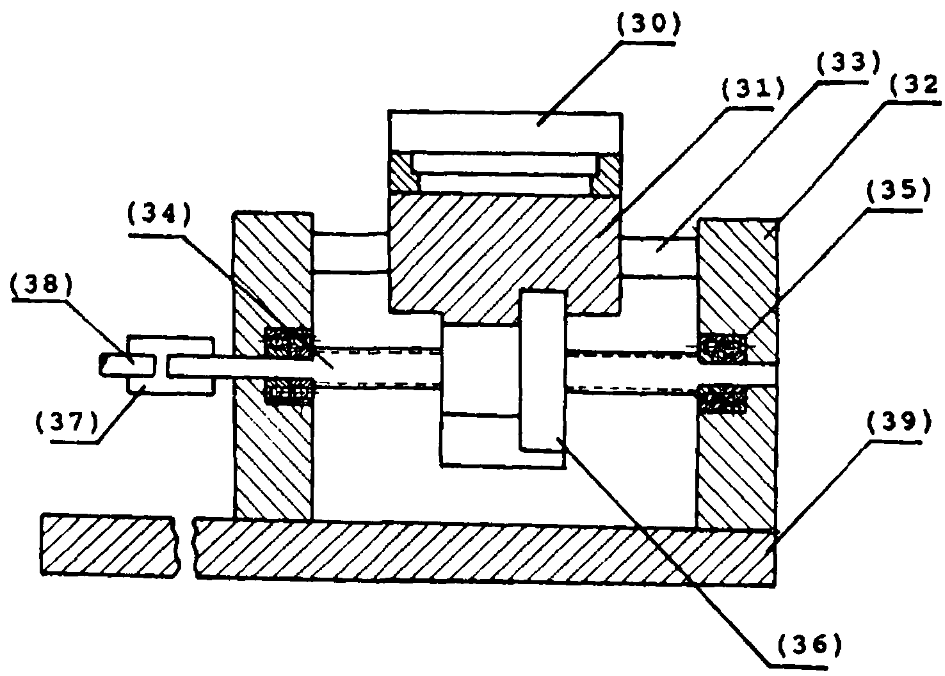


Figure (4-9) SLIDING MECHANISM

(30)......U MASS

(31).....CARRIAGE

(32).....MASS

(33).....GUIDANCE SHAFT

(34).....LEAD SCREW

(35).....BEARINGS

(36).....LEAD SCREW

(37).....COUPLING

(38).....MOTOR SHAFT

(39).....GENERAL BASE

4-3-2-1 Motors

(1)- *The basic DC motor operation*

Direct-current motors (DC) are one of the most widely used in control systems and they have many applications in computer peripheral equipment.
The DC motor is basically a torque transducer that converts electrical energy into mechanical energy The torque developed on the motor shaft is directly proportional to the field flux and the armature current The relationship between the developed torque, flux, and current is.

$$T_m = k_m - \phi \quad I_a \qquad (4\text{-}9)$$

also, the relationship between the back (emf) and shaft velocity is

$$e_b = k_m \ \phi \ . \ w_m \qquad (4\text{-}10)$$

Equation (4-9) and (4-10) from the basic of DC motor operation, for further detail see ref , [58]

(2)- *Factors of selecting motor*

Two separate figures are needed when selecting a DC motor

(a)- A peak torque, being the sum of acceleration and frictional toques.

(b)- A continuous torque which is the friction component only

the torque produced by the motor is given by :

$$T = k_t . I \tag{4-11}$$

The choice of motor and drive must satisfy the following conditions.

1- The product of k_t and continuous drive current must give the required peak torque

2- The product of kt and continuous drive current must produce sufficient continuous torque.

3- The maximum allowable motor current must be greater than the peak drive current

4- At maximum speed and peak current, the voltage developed across the motor must be less than 80% of the device supply voltage.

The voltage across the motor is given by [59]

$$E = k_e \ w + RI \tag{4-12}$$

(3)- *Torque and inertia calculation*

The moment of inertia of standard mechanical components can usually be calculated quite easily using a few simple formula These formula relate to individual components or parts of a system, and generally easier to use than composite expressions for an entire system which can be rather doubting

The inertia of any mechanical arrangement can be found by considering it as a series of individual elements, starting at the final load to be moved and working back to the motor Once a motor has been chosen We add its own inertia to the rest of the system

Most cylindrical components (shaft, discs, pulleys etc) will be made of steel or aluminium, in which case the inertia can be calculated very quickly Use the general formula for other materials For hollow cylinders, calculate the inertia as the difference of two solid cylinders.

For " metric system"

For steel $J = D^4 L/1300$ **(4-13)**

For aluminium $J = D^4 L/3800$ **(4-14)**

Appendix (A4-1), gives the formula which are used for this calculations

(4)- *Technical specification of selected motors*

A steel geared " medium duty " motor is selected to drive the clamping and rotating mechanism

This motor has the technical specification given in Appendix (A4-2), and bought from Radionics, Herberton road Dublin 12

While a heavy duty motor is selected to drive the sliding mechanism and it bought from the same company this motor has the technical specification given in the Appendix (A4-3)

4-3-2-2 Linear Variable Differential Transformer(LVDT)

A basic electronic measuring system is shown in figure (4-10) It consists of

(1)- The transducer (or sensor), which converts the measurand into a usable electrical output

(2)- The signal conditioner, which converts the transducer output into an electrical quantity suitable for proper operation the display device

(3)- The power supply, which feeds the required electrical power to the signal conditioner, provides excitation for all except " self generating " types of transducers, and may also furnish electric power to certain types of display devices

(4)- The display device (or read out), which displays the required information about the measurand [15]

An important displacement transducer extensively used for many industrial and medical applications, the linear variable differential transformer [13], [15] Usually referred to LVDT or sometimes a differential transformer

(a)- The basic operation of the LVDT

This sensor is a transformer with a single primary windings and two identical secondary windings wound on a tubular ferro-magnetic former The primary winding is energised by an a c voltage of amplitude V_s, frequency fs Hz, the two secondaries are connected in

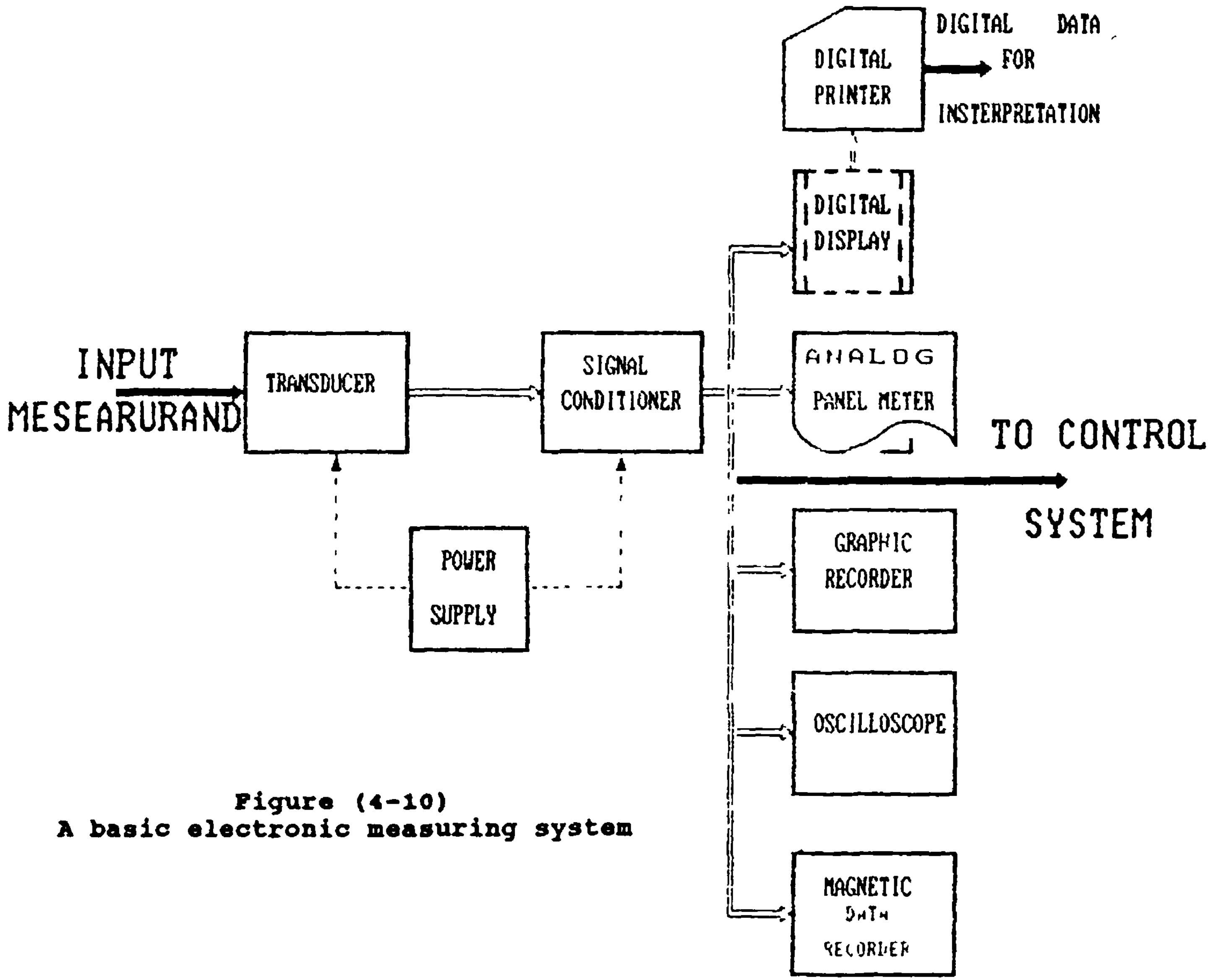


Figure (4-10)
A basic electronic measuring system

series opposition, so that the output voltage

$$V_{out} \text{ X Sin } (2 \text{ x } 3\ 14 \text{ x fs t} + 0)$$

is the difference ($V_1 - V_2$) of the voltage induced in the secondaries A ferromagnetic core or plunger moves inside the former, this alters the mutual inductance between the primary and secondaries.

With the core movement the secondary voltages are ideally equal so that Vout + 0. With the core in the former, V_1 and V_2 change with core position x, causing amplitude V_{out} and phase 0 to change, the relationships between Vout, 0 and x are shown in figure (4-11) We see that there is a null point c at the centre of the sensor (x =1/2 L) where $V_{out} = 0$ (ideally), here there is equal coupling between the primary and secondaries, so that $V_1 = V_2$ At the points A and B equal spaced either side of the null point, V_{out} has the same value V_o However, at A the output voltage is 180 out of phase with the primary voltage i e $0 = 0°$, ($V_1 > V_2$) Non-linear effects occur at either end (D and E) as the core moves to the edge of the former [11]

(b)- Characteristics of the LVDT

Characteristics of the LVDT include the following

(1)- Resolution is excellent

(2)- Hysteresis is very small

(3)- Response and dynamic characteristics are excellent

(4)- Temperature characteristics are excellent

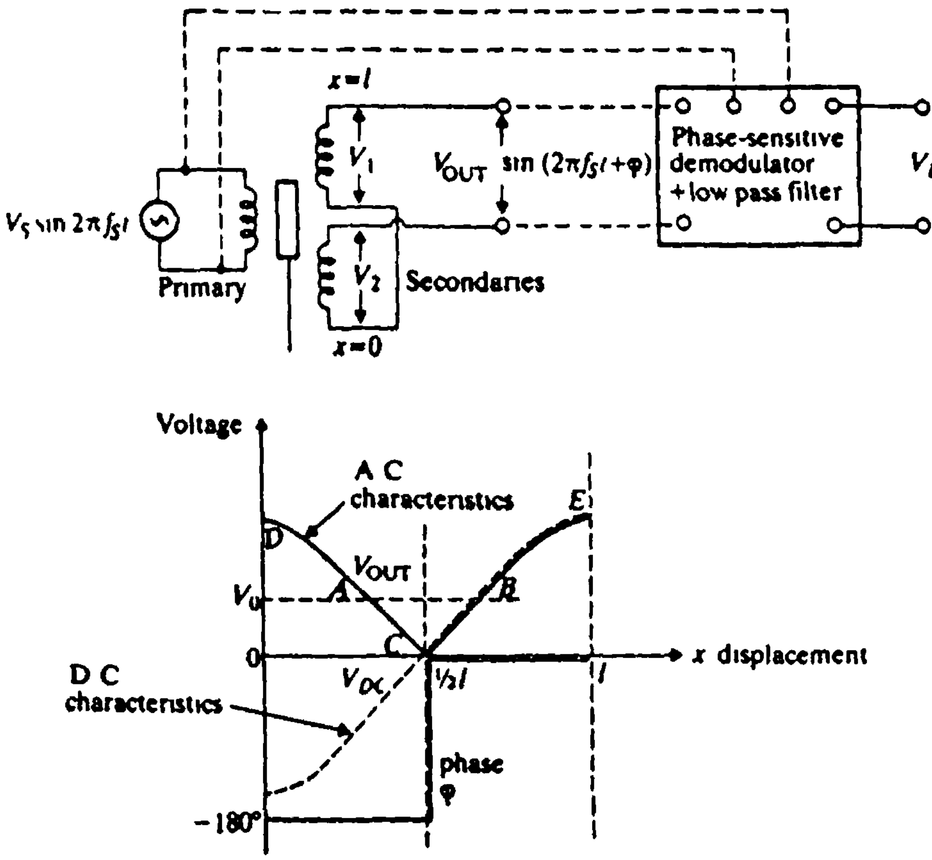


Figure (4-11)
Linear Variable Defferential
Transformer (L.V.D.T)

(5)- Vibration and environmental sensitivity are good.

(6)- Linearity, mechanical overload capabilities, and life are excellent [13].

(c)- The major advantages of the LVDT.

The major advantages of the linear variable differential transformer are as follow

(1)- There is no frictional contact between the core and the coil and therefore the LVDT has a longer life than a potentiometer

(2)- Infinite resolution [62]

(d)- Technical specification of selected LVDT

Selected LVDT was of type of GT x 2500, it has the technical specification shown in the Appendix (A4-4) This sensor was purchased from R D P electronic Ltd Wolverhampton, England.

The complete information are given by its catalogue This sensor has an adequate range, resolution, and accurate enough for the measurement

4-4 Computer interfacing and signal processing

In our world variables are temperature, pressure, etc , but our computer can only cope with encoded binary (digital) numbers which represent the variables The first step in the chain from any real world variable to a number in the computer is called transducer, or occasionally a sensor.

4-4-1 Computer interfacing

With all the signals in digital form it remains to connect to the computer and have them read in. The connection point is what is traditionally regarded as an interface

Definitions of an interface are difficult as the term covers so much An interface is a boundary between a control device and a connected device or devices which may not include controlling logic, such as a transducer, a peripheral or another processor

An interface is the definition of the logical, electrical and physical properties of the boundary, but the definition has to be extended further to protocols as any interface these days is combination of both hardware and software

The balance of hardware and software can usually be varied, one way giving greater speed of operation and the other way reducing the cost of the connection The interface does not have to be a single boundary as the definition can be of the visible boundaries surrounding some logic private to, and include in, a so-called thick interface.

The organization of the interfaces and the input/output system in general has a bearing on the architecture of the overall system The use of interfaces and standard interfaces in particular, also impacts on high-level languages which until very recently have been notable for their inadequate handling of Input/Output the use of rigously developed interface standards could be mirrored by the development of standard language constructs to permit the software parts to be high level rather than the assembly language addition needed for full BASIC, FORTRAN or PASCAL input/output.

4-4-2 Signal conversion DIGITAL TO ANALOG (D/A)

Computers only operate on digital values and so any analog signals, like most signals from the real world, must be converted to the nearest digital representation to the desired accuracy (plus or minus one half of the least significant bit) the bounded infinite set of analog values is quantized to a desecrate set of digital values by comparing the unknown input with known digital equivalent values to find the nearest match

Thus before, considering analog to digital conversion we should look at digital to analog converters which could provide the known digital equivalent values as output.

D/A converters either provide voltage or current outputs but for greatest speed they switch currents internally. Current steering is faster because the reference current is not switched on or off and the only significant voltage changes are the required ones

The basic technique is to apply the digital pattern via a set of switches on to a precision resister network to which an accurate reference voltage source is connected The output then is the sum of the selected current and is output either as the current or converted by an operational amplifier to voltage

4-4-3 Signal conversion Analog to Digital (A/D)

Most operations involving computers have two extremes for the performance of their algorithms They can be fully parallel or fully serial There are also many intermediate forms, in many cases, combining serial and parallel computation

Analog to digital (A/D) conversion is no exception, the fastest converters are fully parallel, the cheapest fully serial

The An A/D converter using a serial algorithm needs the ability to generate the complete set of discrete analog values one at a time The unknown input is then compared with these, in some order, to determine which is nearest approximation Hence, a D/A converter and a comparator are the only necessary hardware elements [63]

4-4-4 Interfacing the motors and the LVDT

A special arrangements were designed in order to control motors and processing the different signals, analog and digital, considering the various previous principles and requirements

Figure (4-12), illustrates these arrangement as two sections, the first one concern motors and consists of two motors, amplifier, protection box and digital to analog converter is connected to personal computer

While the second section consists of the LVDT, transducer amplifier, protection box Analog to digital converter and the same personal computer which is connected to digital printer

Also, two meters were used to monitor the change in the output and input The descriptions of these elements are as follows

4-4-4-1 Signal conversion Digital to Analog (D/A)

- DAC-02 Description

The converter used to change the digital signal coming from the computer to control the movement and velocity of the motors was of type DAC-02

This card consists of two separate double buffered 12 bit multiplying D/A channels plus interface circuity The D/A converters may be used with a fixed D C references as conventional D/A's on board references of -5 V and -10 V provide output ranges of 0-5 V, 0-10 V, +/-5 V and +/-10 V , and 4-20 mA for process control current loops Alternatively, the D/A's, may be operated with a variable or A C reference signal as multiplying D/A's, the output

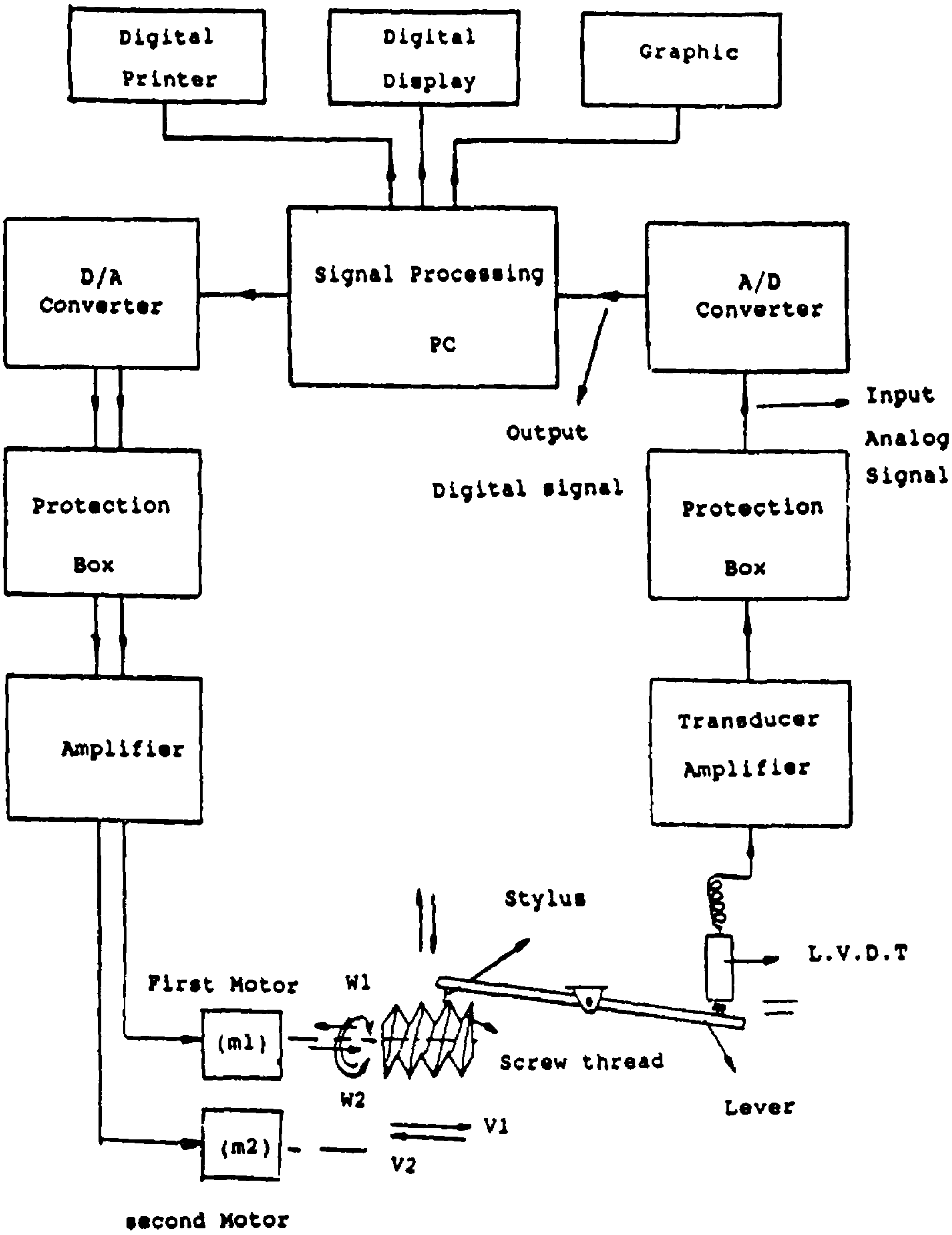


Figure (4-12)

Block diagram of the inspection system.

is the product of reference and digital inputs. With an A C reference, the unipolar outputs provide 2 quadrant multiplication and the bipolar outputs provide 4 quadrant, operation 12 bit accuracy is maintained up to 1kHz. Since data is 12 bits, data is written to each D/A in 2 consecutive bytes The first byte is the least significant and contains the 4 least significant bits of data The second byte is the most
significant and contains the most significant 8 bits of data The least significant byte is usually written, first and is stored in an intermediate register in the A/D, having no effect on the output When the most significant data and presented " broadside " to the D/A converter thus assuring a signal step update This process is known as double buffering
The DAC-02 is packaged on a 5" long (half-slot) board suitable for use in all models of IBM P C S it is addressed as an I/O device using 8 I/O locations, and may have its I/O address set by means of an on-board DIP switch to any 8 bit boundary in the 255-1023 (decimal) I/O address space The board uses the internal +5V, + 12V and 12V computer supplies and consumes 850 milli-watts of power [64] Figure (4-13), illustrate this card While, Appendix (A4-5), gives its the specification

4-4-4-2 Signal conversion ANALOG TO DIGITAL (A/D)

Without this board signals from the linear variable differential transformer (L V D T), will have no

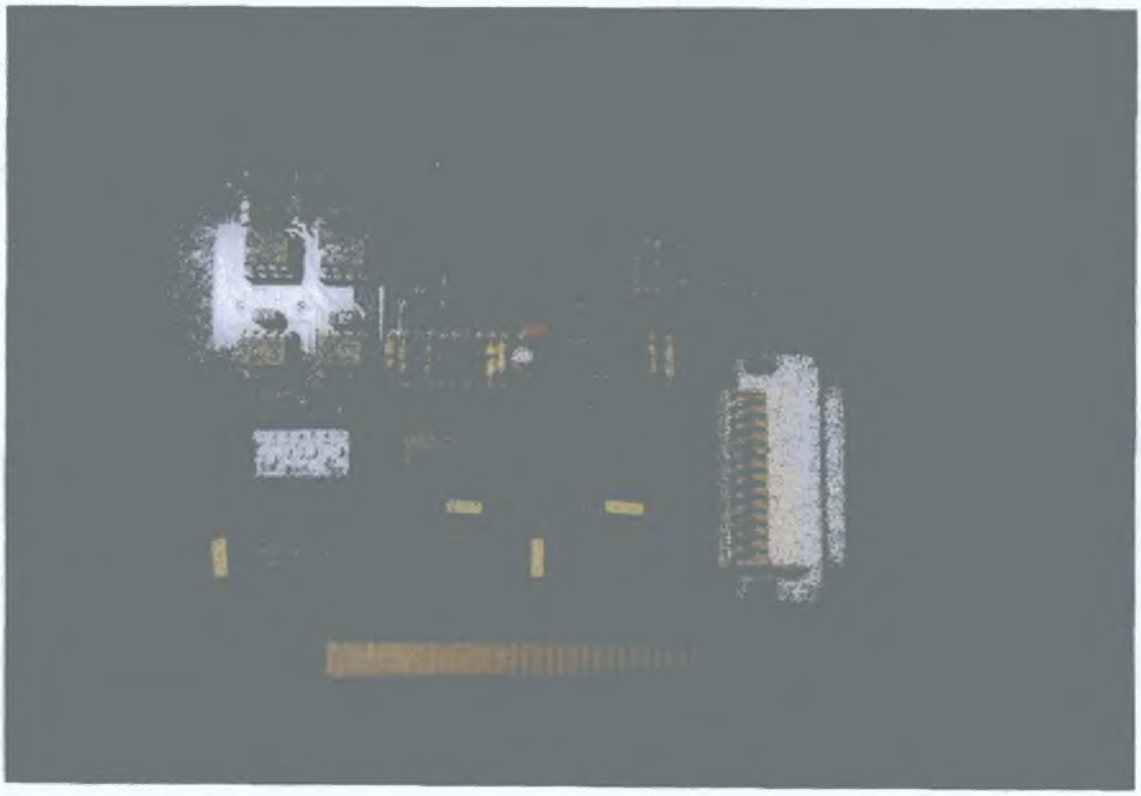


Figure (4-13)

DIGITAL TO ANALOG (D/A).

DAC-02

meaning, therefore a converter of type DASH-8 converts the analog signals into digital one was selected.

- Description of the DASH-8

The dash-8 is an 8 channel 12 bit high speed converter and timer/counter board IBM.PC The DASH-8 board is 5" long and can be fitted in a " half " slot . All connection are made through a standard 37 pin D male connector that projects through the rear of the computer. The following functions are implemented on the DASH-8

(1)- An 8 channel, 12 bit successive approximation A/D converter with sample / hold The full scale input of each channel is ended with a common ground and can withstand a continuous over load of +/- 30 volts and brief transients of several hundred volts All input are fail safe i e open circuit when the computer power is off. A/D conversion time is typically 25 microsecond (35 microsecond max.) and depending on the speed of the software drive, through puts of up to 30.000 channels /sec are attainable

(2)- An 8253 programmable counter timer provide periodic interrupts for the A/D converter and can additionally be used for event counting, plus and wave form generation, frequency and period measurement etc There are three separate 16 bit down counters in the 8253 One of these is connected to a submultiple of the system clock, and all I/O functions of the remaining two are accessible to the user

(3)- 7 bit of TTL digital I/O are provided composed of one output part of a bits and one input port of 3 bits

(4)- Precision +10 00 Volts (t/-0/v) reference voltage output is derived from the A/D converter reference

(5)- An external interrupt input provided the select any of IBM P C interrupt levels 2-7 and allows user programmed interrupt routines to provide background data acquisition or interrupt driven control The DASH-8 includes status and control registers that make interrupt handshaking a simple procedure The interrupt input may be externally connected to the timer/ counter or any other trigger source.

(6)- IBM P C buss power (+5,+12, 8-12v) is provided along with all other 1/0 connection on the rear connector This makes for simple addition of user designed interfaces, input signal conditioning circuits, expression multiplexer etc Figure (4-14), illustrates this card, [65] While Appendix (A4-6), gives its specifications

4-4-5 Specification of transducer amplifier type S7M

The S7M is an oscillator/demodulator (synchronous) providing excitation and signal conditioning for a wide range of inductive transducers, or when fitted with an

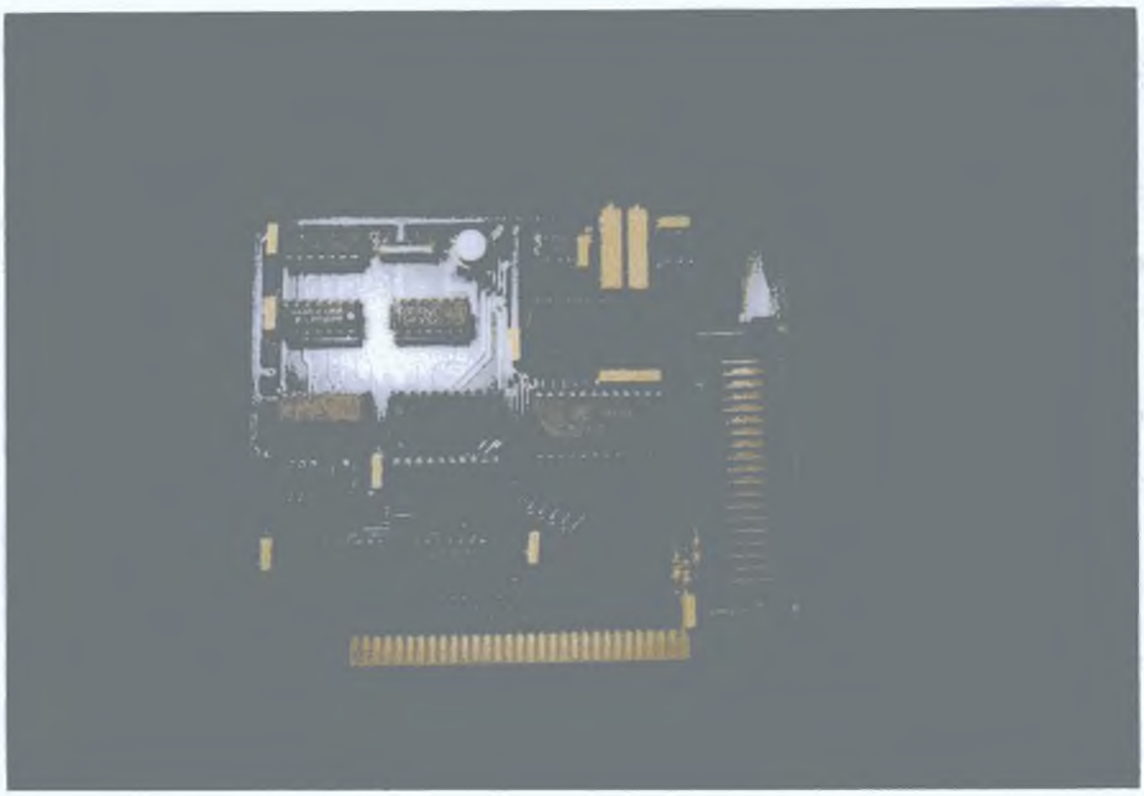


Figure (4-14)

ANALOG TO DIGITAL (A/D).

DASH-8

input option card, for resistive strain gauges A +/-10 output is obtainable with signal inputs in the range 50 mV to 20V (lower with option z) High current output options provide +/-10 V at 100 mA or 4-20 mA

Internal controls set gain and zero output (with up to 100% suppression) Also included are zero/run switch, over-range indicator (LED) and mounting pins for easily changing bridge input option resistors and frequency selection capacitor The input option includes a(shunt), calibration switch connecting an internal precision (59K) resistor, with an on-board relay allowed remote CAL operation Selector links allow operation from 120 or 240 a c supplies

The unit is suitable for use with strain gauges and the complete range of R D P pressure and AC-LVDT Transducers [66] The technical specification of this amplifier is given in Appendix (A4-7)

4-5 Calibration

There are two kinds of calibration The first one is performed by the manufacturer, and the second is performed by the users Motors, amplifiers, converters, and transducers require a special calibration

The transducer, only will be considered as an example Transducer manufacturer calibration certificate includes linear range, cal tem, cal load, sensitivity and linearity The user calibration aims to find out a certain formula to be used for a specified purpose

The linear variable deferential transformer (LVDT) produces an electrical output proportional to the displacement of a separate movable core

The output voltage of an (LVDT) is a precisely linear function of core displacement over a specified range of motion Consequently, a plot of output versus core displacement is essentially a straight line within the specified range of motion Beyond the nominal linear range, the output begins to deviate from a straight line in a gentle curve User calibration is accomplished to indicates the linear range Then using an accurate measuring instrument, the relationship among the output and displacement is found [13]

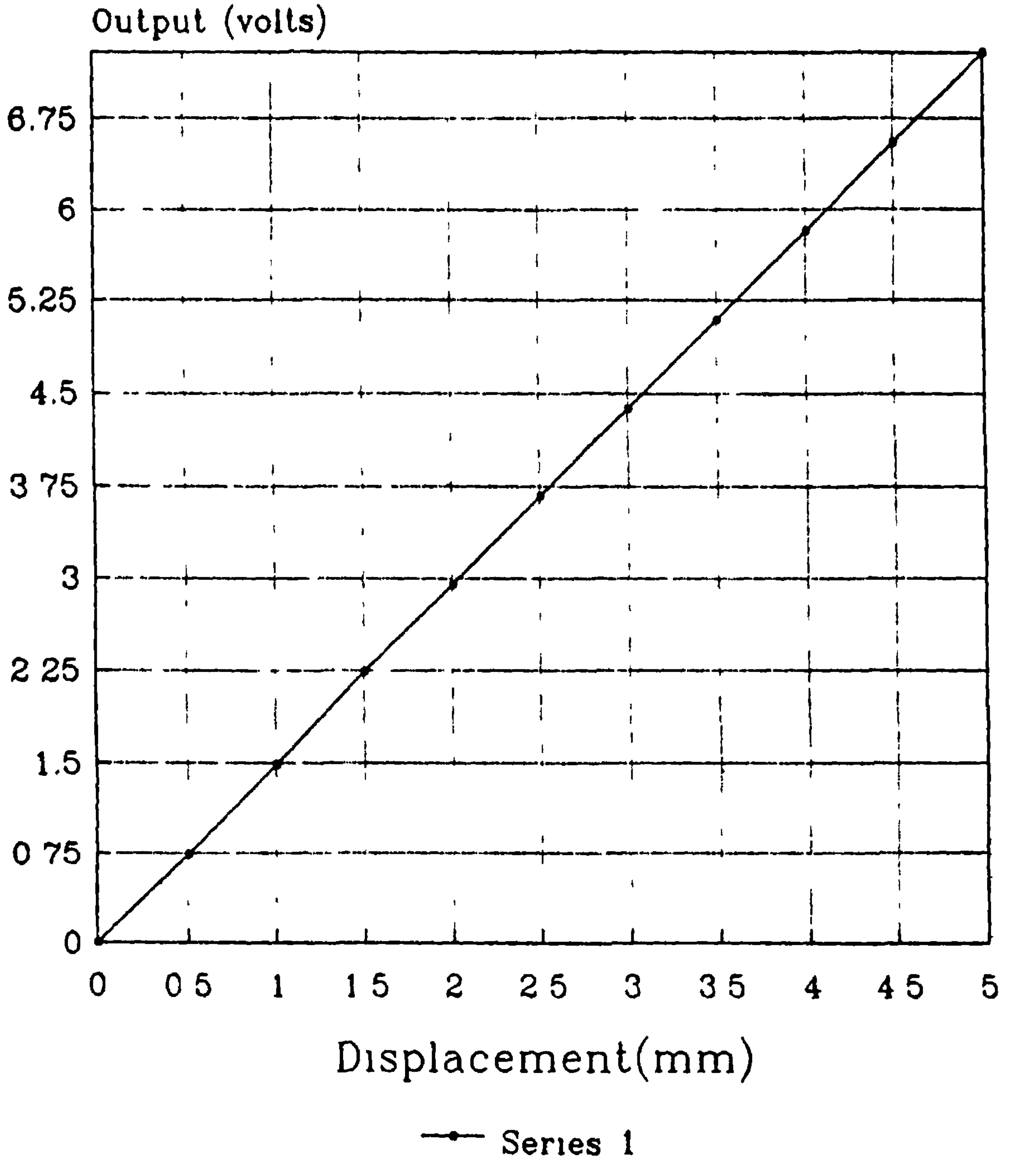
Theoretical, relationship between output and displacement is in the form of linear equation, in general it has the following form:

$$Y = F(x) \tag{4-15}$$

Calibration of GT X 2500, was repeated five time, Figure (4-15) shows that the calibration result is of a linear form as the theoretical one

4-6 Software design

Two separate programs were designed to fit the purpose of automatic inspection, the first one is to control the motor movements at a certain time to a



(L V D T),calibration -2- **Figure (4-15)** certain positions. While, the second has different tasks, like processing computing, comparing, displaying, printing and plotting the results these programs were written in the BASIC language and they may be also converted to any other languages.

CHAPTER FIVE

5-EXPERIMENTAL RESULTS

5-1 The measuring principle.

The measuring principle of the automatic measuring system, is based on moving a stylus at constant velocity across the thread profile or the helix path The rise and full of the stylus is detected electronically using an electromechanical sensor, the signal is then amplified and interfaced to a personal computer

Figure (5-1), shows the relationship between the bolt movement and the stylus displacement, for the case of form inspection, in which the bolt moves at a constant velocity V_2, while the stylus which is free to move vertically, follows the thread form, thus the rise and falls of the stylus provide the trace of the thread form

Also, figure (5-2), shows the relationship between the bolt movement and the stylus displacement for the case of helix inspection In this case the bolt rotates with a constant angular velocity, at the same time, it is moving with a constant linear velocity V_1, while the stylus is free to move only in the vertical direction

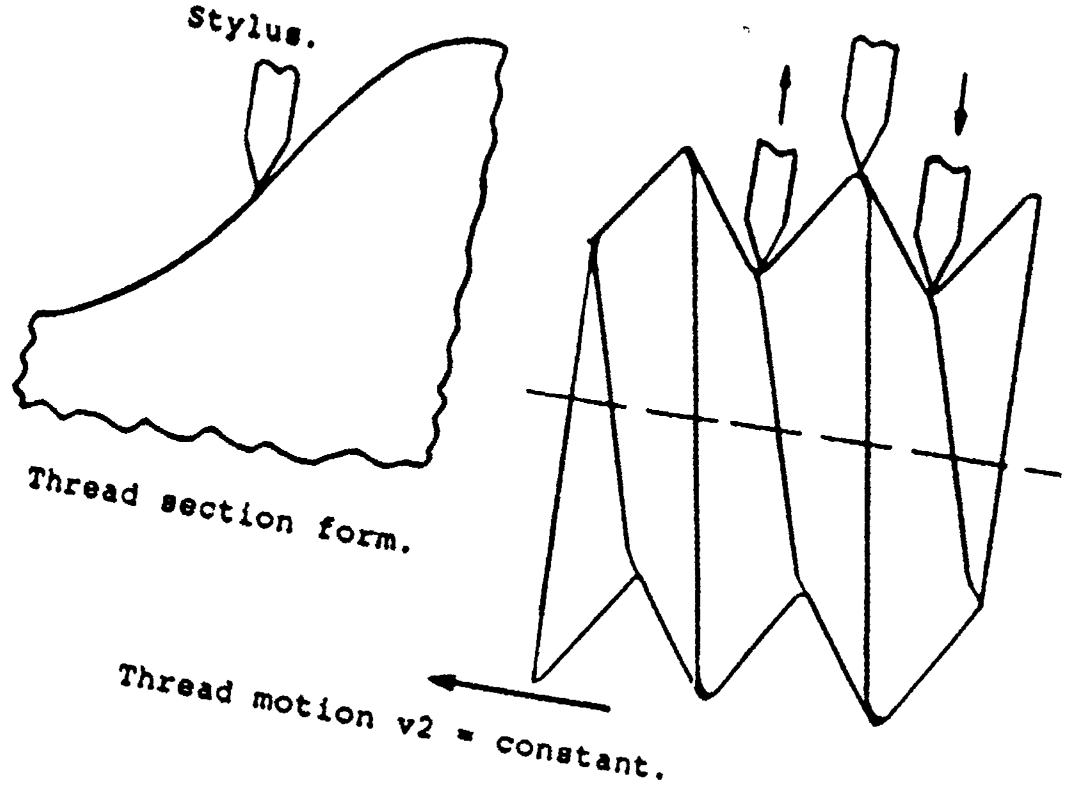
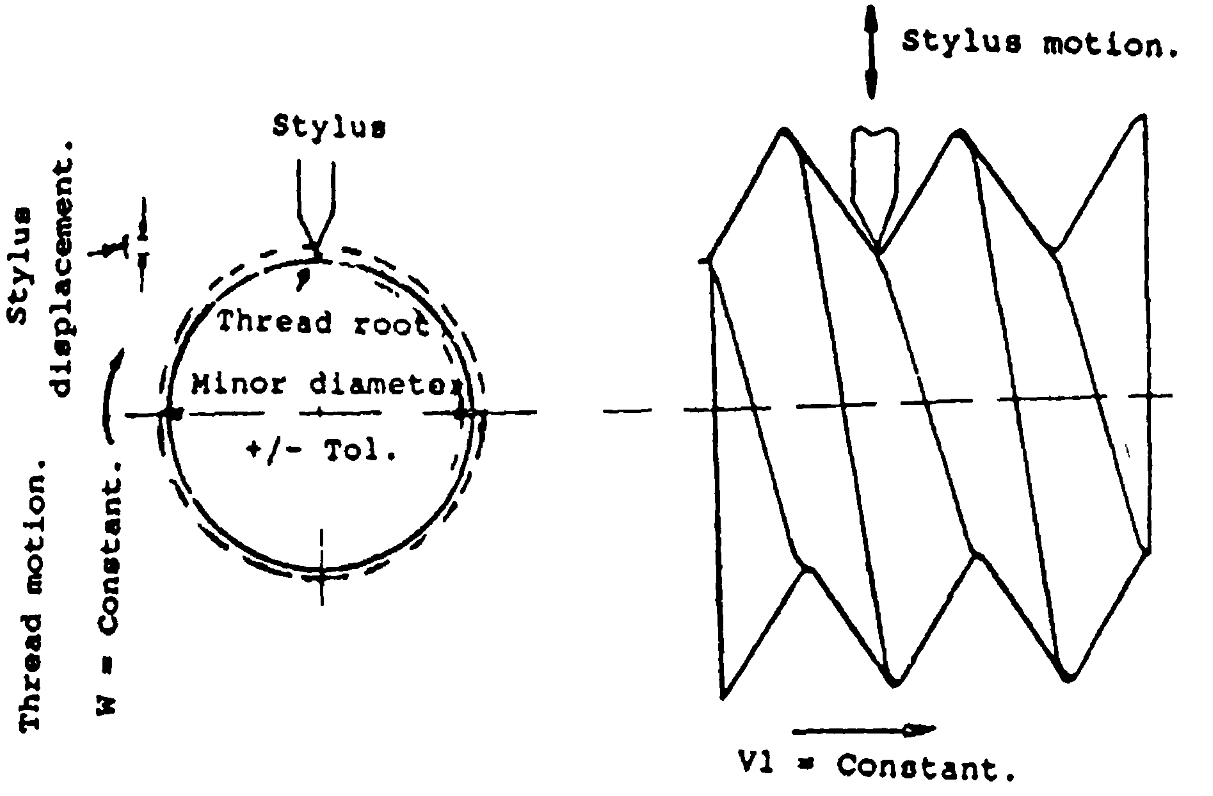


Figure (5-1)



Stylus motion.
Stylus
Stylus
displacement.
Thread root
Minor diameter
+/- Tol.
Thread motion.
W = Constant.
V1 = Constant.

Figure (5-2)

5-2 The operational cycles

The inspection process starts from the initial position and the results are displayed, immediately at the end of each operational cycle.

The operational cycles of the thread measuring system consists of two basic cycles. These are·

(1)- The helix path inspection cycle.

(2)- The thread form inspection cycle.

And each one of them, consists of the following steps

1- ***Clamping the object***
2- ***Stylus contact***
3- ***Generating the linear and the angular motions***
4- ***Generating the linear motion***
5- ***Releasing the object and displaying the results***

5-2-1 Clamping the object

The first step of the operational cycles, is clamping the bolt between the fixed and movable jaws Figure(5-3a), shows that, the movable jaw should be moved from a specified point a_1 to another point a_2 in order to perform the clamping step according to the specified design pressure The difference between a_1 and a_2 is always constant and equal to X_1 for the same type of

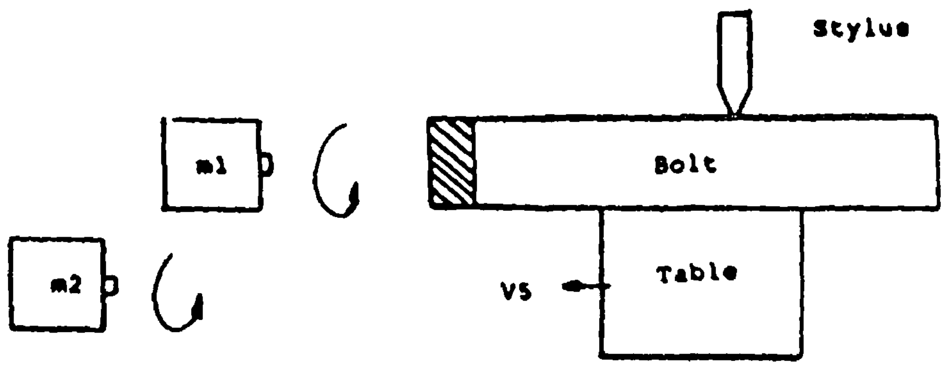


Figure (5-3a)

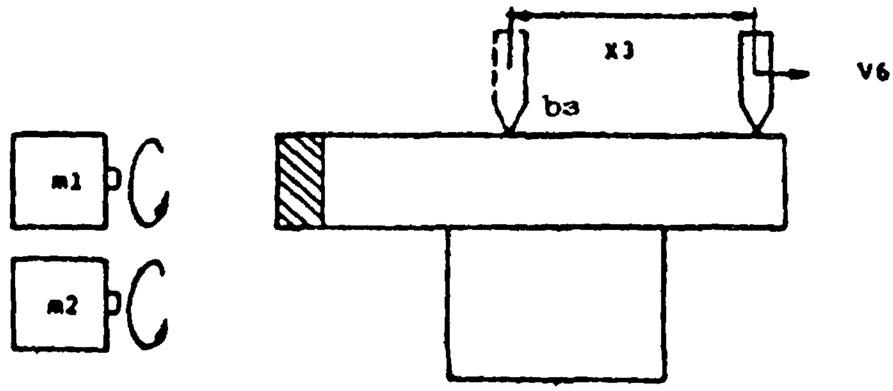


Figure (5-3b)

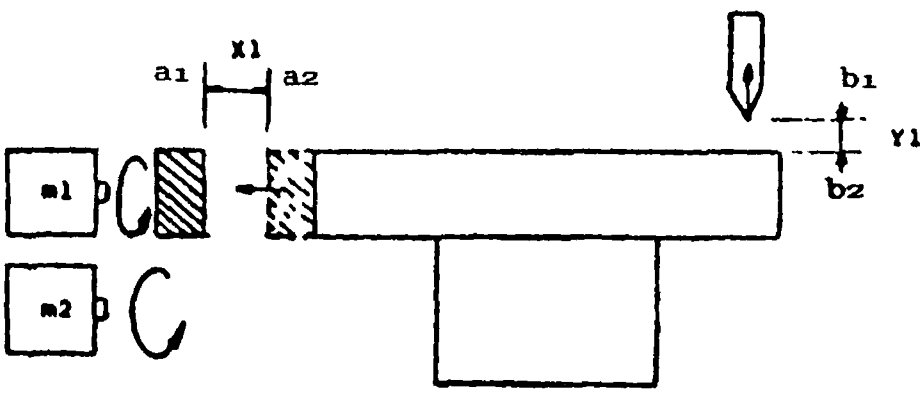


Figure (5-3c)

The thread form inspection cycle.

bolt The previous movement is provided by motor number one (m_1) as a specified key is pressed

The motor starts rotating causing advance movement of the movable jaw which moves linearly by the effect of the internal guidance inside the fixed cylinder, Until it gets to the second point a_2

Different velocities can be applied to the movable jaw, one of these velocities is V_2 which equals 25 mm/sec and represents the maximum linear velocity

Also, the distance X_1 between the point a_1 and the point a_2 can be increased or decreased and it depends on the bolt size

5-2-2 Stylus contact

The stylus contact, represents the second step of the operational cycles, see figure (5-3b).

As soon as the clamping jaw advances with a constant velocity V_1 to clamp the bolt, the stylus advances with a constant velocity V_2 from point (b_1) to point (b_2) which is the reference point of the measuring system

Also, the difference between point b_1 and point (b_2), always equals to the constant distance Y_1.

5-2-3 Generating the linear and the angular motions.

This step aims to perform the helix path inspection Once the stylus approaches the reference point at the root of the thread, it triggers a micro switch for starting motor number two (m_2), as shown in figure (5-3c), which provides the linear motion to the bolt table thereby moving it with a constant velocity. The bolt rotates with a constant angular velocity, at the same time the stylus moves along the helix path, from point b_2 with a constant linear velocity V_4 until it gets to point b_3, which represents the end of this step

The inspection time and the travelling distance are controlled through the software which are designed with the capability of providing a number of different angular and linear velocities which are required to select the optimum conditions for operating this system

5-2-4 Generating the linear motion

When the stylus travels to point b_3, it triggers again another micro switches. The first micro switch stops motor number one (m_1), while the second micro switch reverses the rotating direction of motor number two (m_2). The stylus traces the form of the thread with a constant velocity V_6 when it moves from point b_4 to b_1 as shown in figures (5-4a) and (5-4b).

5-2-5 Releasing the object and displaying the results.

As soon as, motor number two (m_2), stops at point

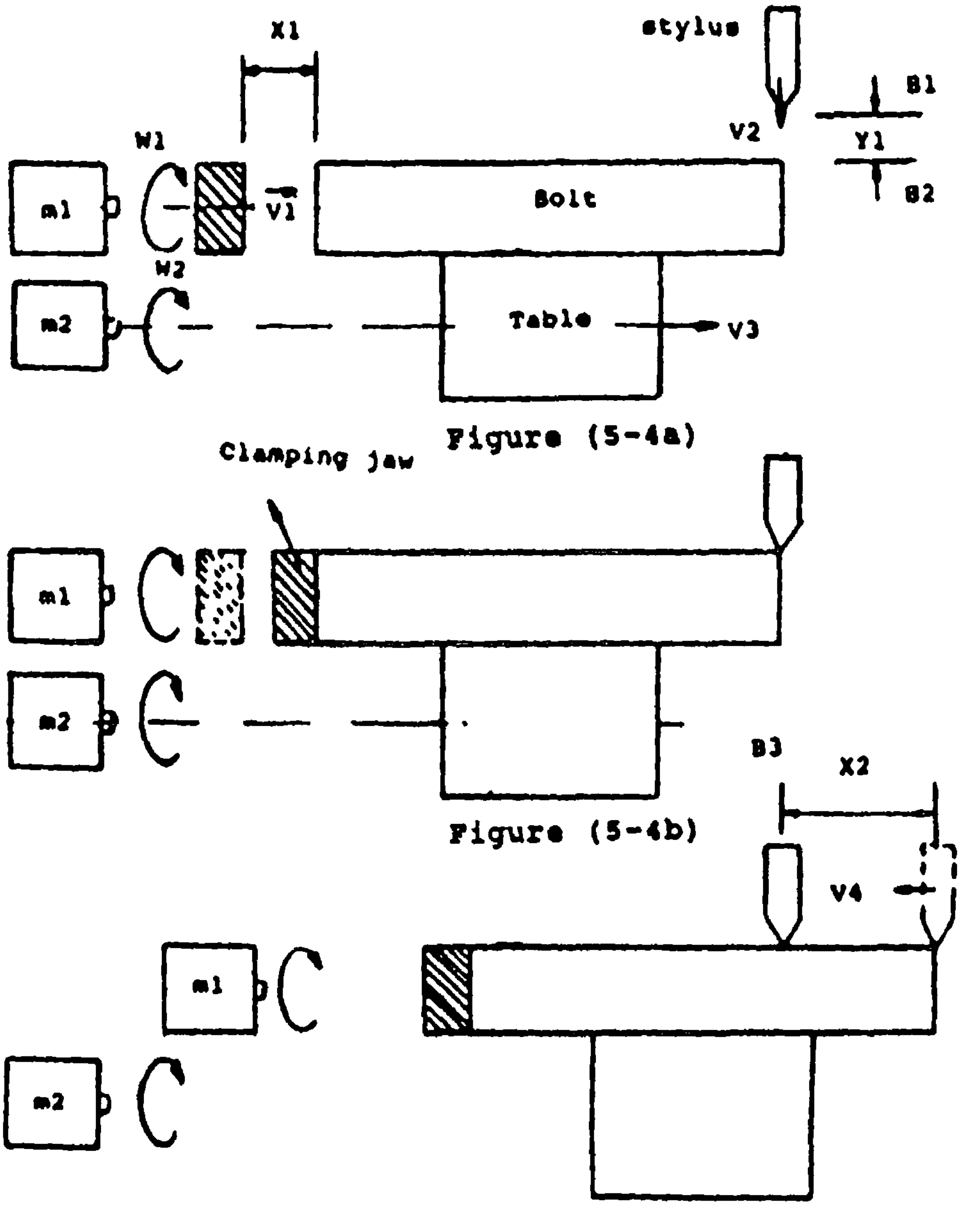


Figure (5-4a)

Figure (5-4b)

Figure (5-4c)

The helix inspection cycle.

b1, an order is given to motor number one (m_1) to start rotating in order to withdraw the movable jaw to its initial position. The same operatin is performed on the stylus, and the results of inspecting either the helix path or the form are displayed on the screen and then plotted or printed as required. See figure (5-4c)

5-3 Experimental procedure.

The experimental procedure includes, calibrations and recommendations.

5-3-1 Calibrations

Two different kinds of calibration procedures are required for the automatic measuring system. The first calibration procedure is for the electronic elements which is necessary for developing the software And the second calibration procedure is for the mechanical mechanisms. This is necessary before starting the operational cycles for each bolt size.

(1)- Calibration of the electronic elements

One of the electronic elements which requires. Calibration is the linear variable differential transformer (LVDT). The calibration of this element is the most important, because it affects the software and signal processing. The (LVDT) calibration is required to find out the relationship between the output of the (LVDT) so an electrical signals (volts) and the equivalent distance quantity as displacement, gives as metric units This relation has been used for developing the various software

The transducer amplifier S7M has been calibrated to give an output in one direction only, and the calibration procedure is outlined in the manufacturer catalogue

Finally, the two converters (DASH-8 and DAC-02), have been calibrated according to the manufacturer specification

(2)- Calibration of the mechanical elements

The lever and the clamping mechanisms should be calibrated once before operating the system

These calibration are required in order to adjust the distance X_1, between the movable jaw and the side of the bolt Also the same, is required for the distance Y_1, between the stylus tip and the reference point b_2

The main difference between calibrating an electronic element and a mechanical one is that electronic elements are calibrated only once before developing the different software and no need to calibrate them again unless otherwise a defect or failure is detected when they are working

While the mechanical calibration should be repeated when another size of bolt is required to be inspected

5-3-2 Recommendations

The recommendation and notes include the different checking steps which must be accomplished before operating the measuring system These steps form the safety factor of using this system, at the same time, increase the accuracy of the system. Therefore , the following elements must be checked, in order to ensure that they are fixed within the hand tightened forces:

(1)- The general base.

(2)- The stylus .

(3)- The linear variable differential transformer.

(4)- All adjusting bolts.

Also, it is necessary to ensure that all electrical connection are fixed in the right position of these are·

1- Motor connections

2- LVDT connections

After that, it is preferable to try only one operational cycle, and compare the results with the theoretical one to ensure that the measuring system is working within the design specifications.

5-4 Inspected objects.

The inspected objects used for the experimental,

were a set of an ISO metric male screw thread (bolt) These bolts were of 6g class, and their limits and tolerances are given by the table (5), of section four- screw threads **(BS 3643)**. Some of these bolts were manufactured by turning The other were manufactured by rolling

Different sizes of these bolts were inspected using this automatic measuring system. The minimum size was M3. While the maximum size was M36 The specifications of these bolts are given in the **BS** 3643

5-5 Linear and angular velocities.

Two types of velocities are required to perform the form and helix path inspections.

The minimum linear velocity used for form inspection was of range 0 5 mm/sec and the minimum angular velocity used for helix inspection was of range of 1.48 rad/sec While the maximum linear velocity used for form inspection was of range of 2 mm/sec, and the maximum angular velocity used for helix path inspection was of range 6 25 rad/sec other velocities will be illustrated through the figures which are represented our experimental results.

Form and helix path inspections were performed for three different sizes of an ISO metric screw threads (Bolts), these are consequently: M6, M8 and M16.

5-6 Experimental results.

5-6-1 Experimental results of M6

Three different velocities were used to perform the inspections these were 0.5, 0 83 and 1.25 mm/sec While only two angular velocities were used for helix inspection these were. 3 13 and 8.33 rad/sec

5-6-1-1 Form inspection

Figure (5-5), shows the result of inspecting the form of M6 using the lowest velocity 0.5 mm/sec. Also, figure (5-6), illustrates the results of inspecting the same bolt using another velocity 0.83 mm/sec While figure (5-7) represent the results of the same thread using velocity equal to 1 25 mm/sec.

5-6-1-2 Helix path inspection

Figure (5-8), illustrates result of inspecting the helix path of M6 using angular velocity equal to 3 125 rad/sec for one thread only. While figure (5-9), shows the variation of the same bolt for five threads using an angular velocity equal to 3 125 rad/sec.

5-6-2 Experimental results of M8

Five different linear velocities were used to perform the task of form inspections. These are consequently (0.5, 0 83, 1 25, 1 66 and 2) mm/sec.

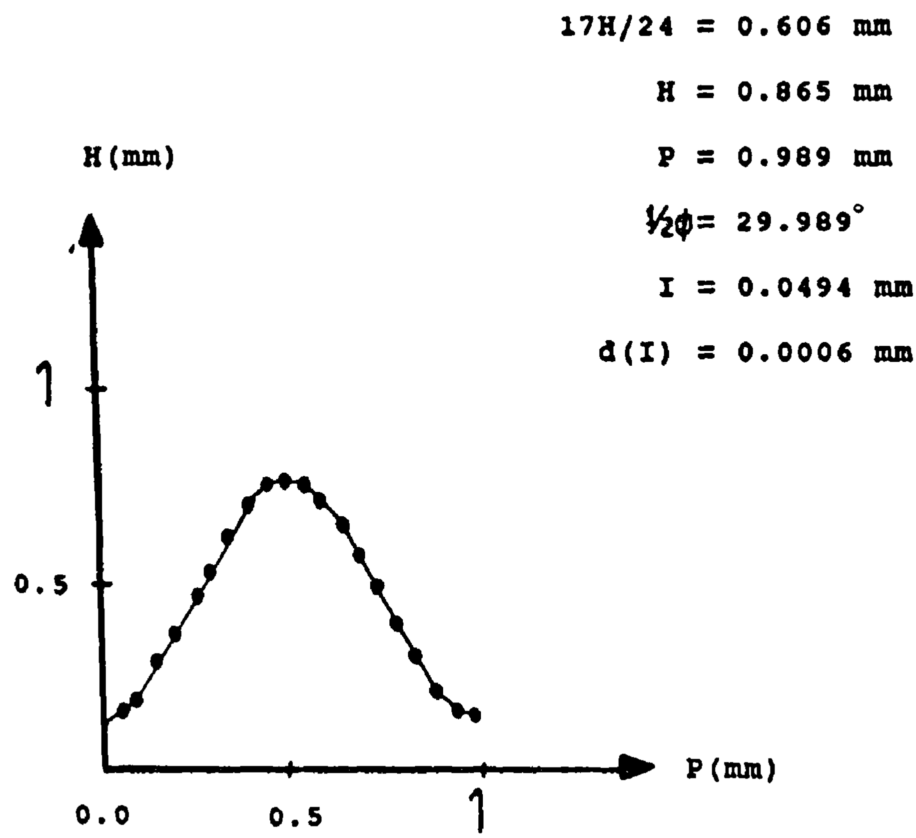


Figure (5-5)
FORM inspection of
M6, velocity 0.5 mm/sec.

17H/24 = 0.604 mm

H = 0.853 mm

P = 0.985 mm

$\frac{1}{2}\phi = 29.989^\circ$

I = 0.0820

d(I) = 0.0013

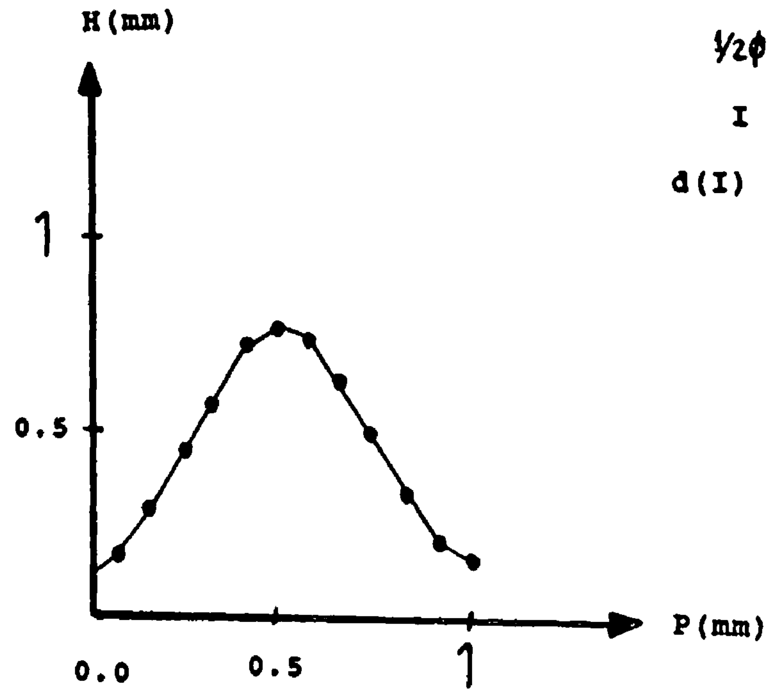


Figure (5-6)
FORM inspection of
M6, velocity 0.83 mm/sec

17H/24 = 0.601 mm

H = 0.848 mm

P = 0.980 mm

$\frac{1}{2}\phi$ = 29.989

I = 0.122 mm

d(I) = 0.003 mm

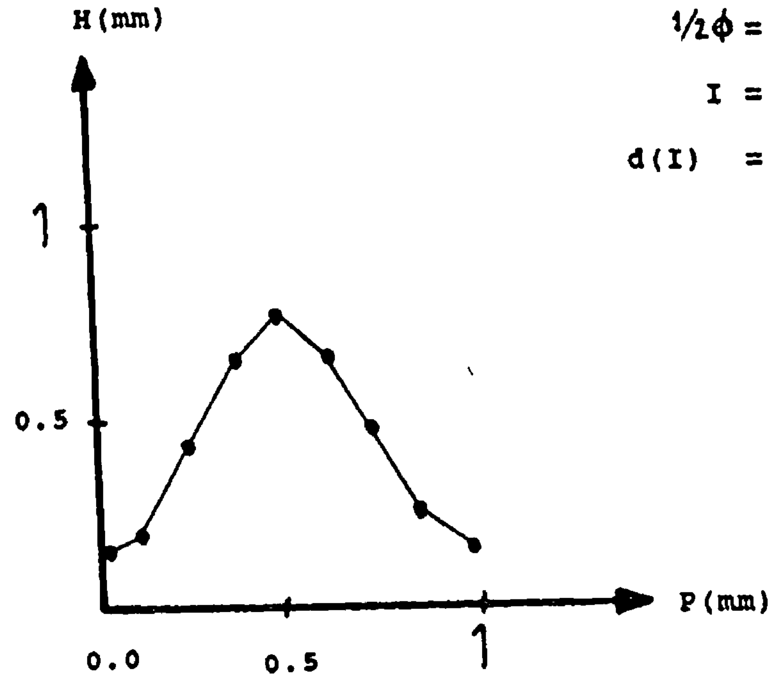


Figure (5-7)
FORM inspection of
M6, velocity 1.25 mm/sec

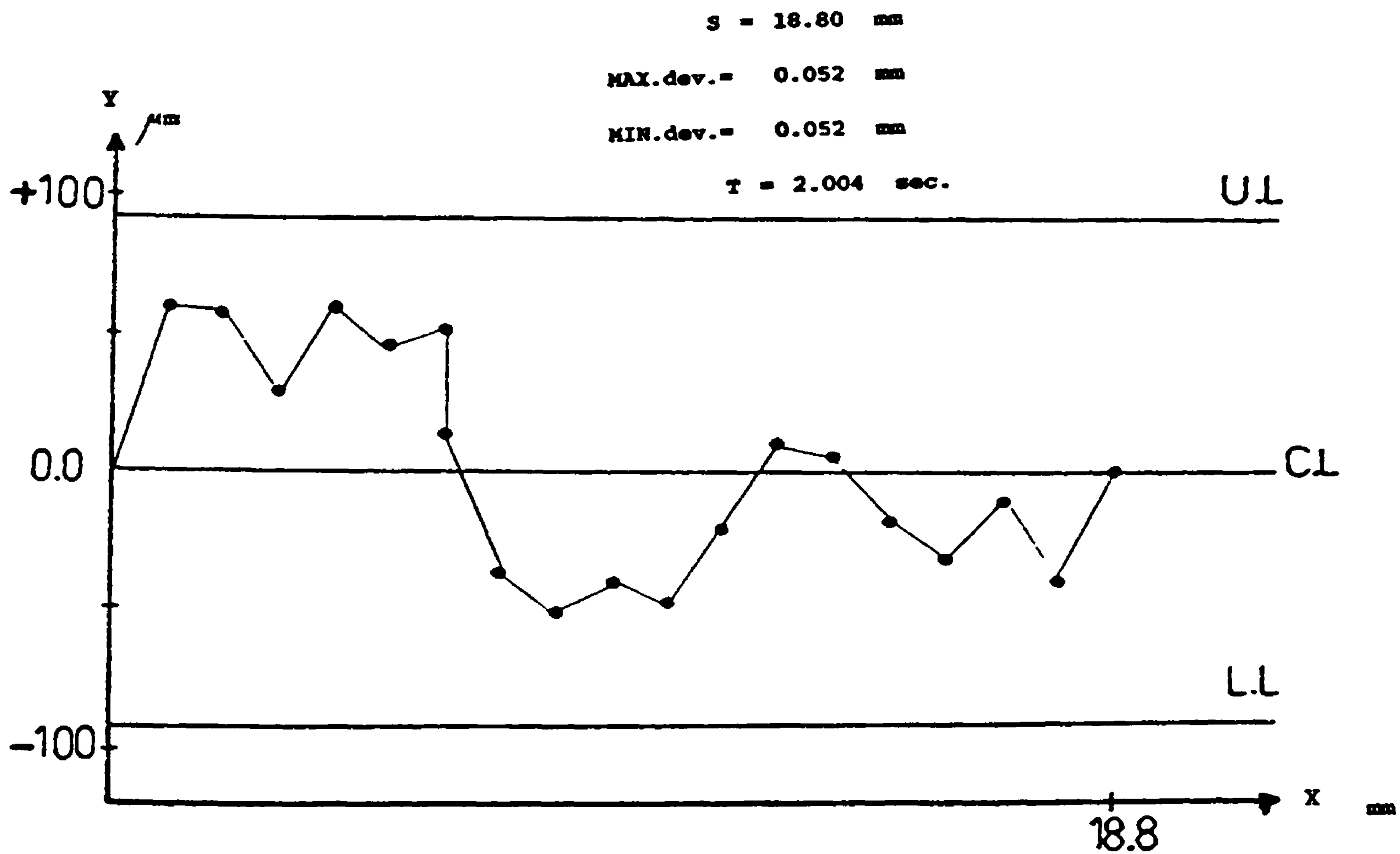


Figure (5-8)
HELIX inspection of
M6, one revolution, w=3.125 rad/sec

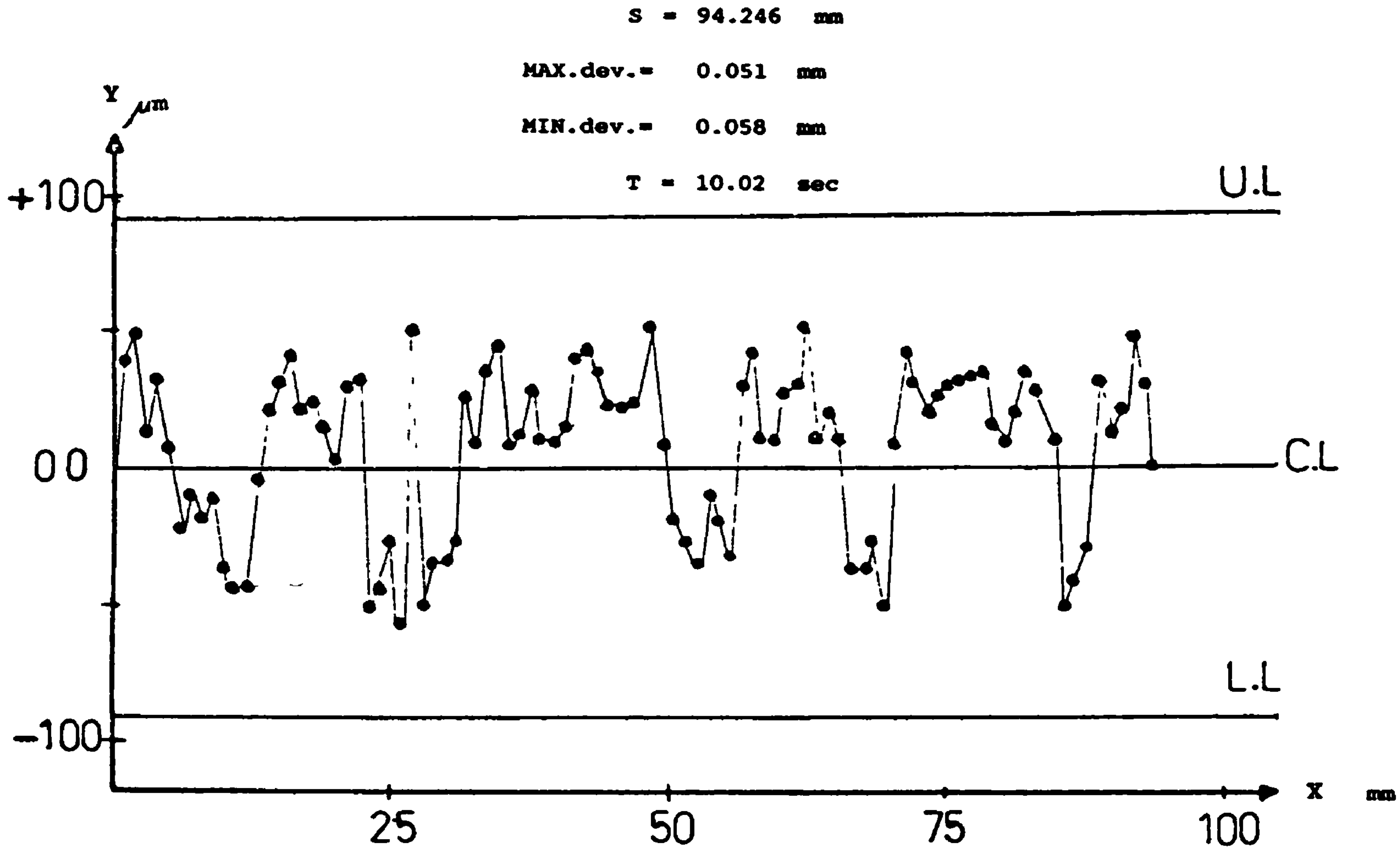


Figure (5-9)
HELIX inspection of
M6, five revolution, w=3.125 rad/sec

Also two different angular velocities were for inspecting the helix path of the same thread, these are

5-6-2-1 Form inspections

Figure (5-10), illustrates the result of inspecting the form of the bolt M8 using a very slow velocity 0.5 mm/sec. The other result which is shown in figure (5-11) represents the slow velocity which equal to 0.83 mm/sec The result of using a medium velocity equal to 1 25 mm/sec can be seen in figure (5-12). The high speed 1 66 mm/sec gives the results shown in figure (5-13)

5-6-2-2 Helix path inspection

Figure (5-14), shows the variation of the helix path due to an angular velocity of 2 84 rad/sec, for five threads, also figure (5-15), shows the variation for one tooth only of the same size and due to the angular velocity w1 The results of using an angular equal to W2 = 6 25 rad/sec , for five threads are shown on figure (5-16), also figure (5-17) shows the result of the same bolt and the same velocity but only for one thread.

5-6-3 Experimental results of M 16

Five different linear velocities used to inspect the form of this size, the same velocities were used to

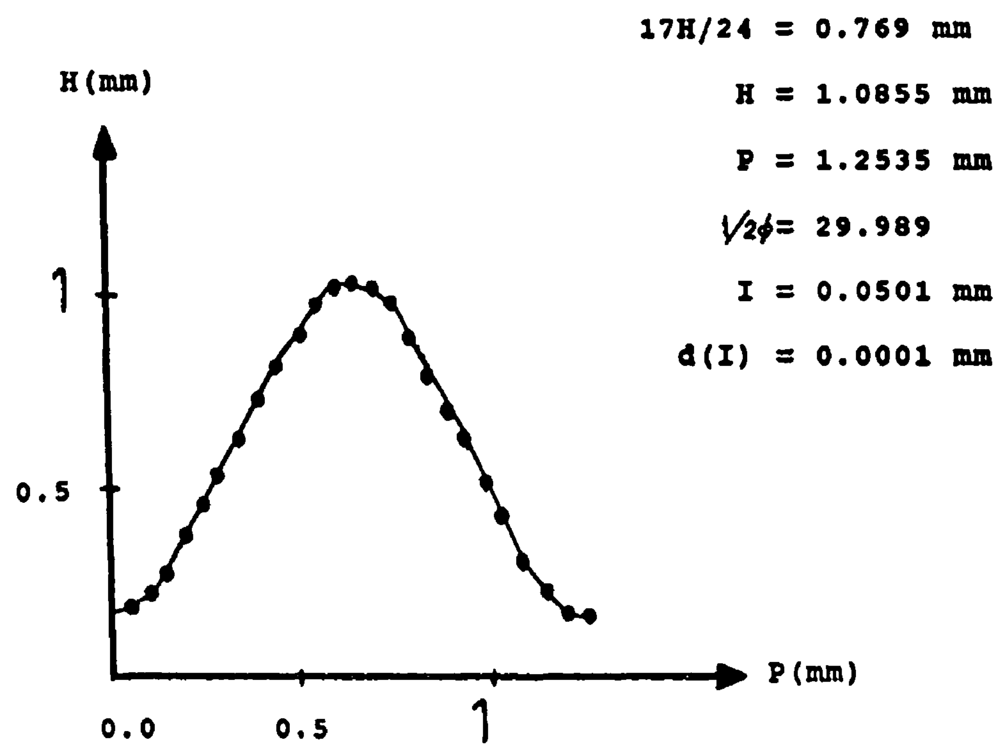


Figure (5-10)
FORM inspection of
M8,velocity 0.5 mm/sec

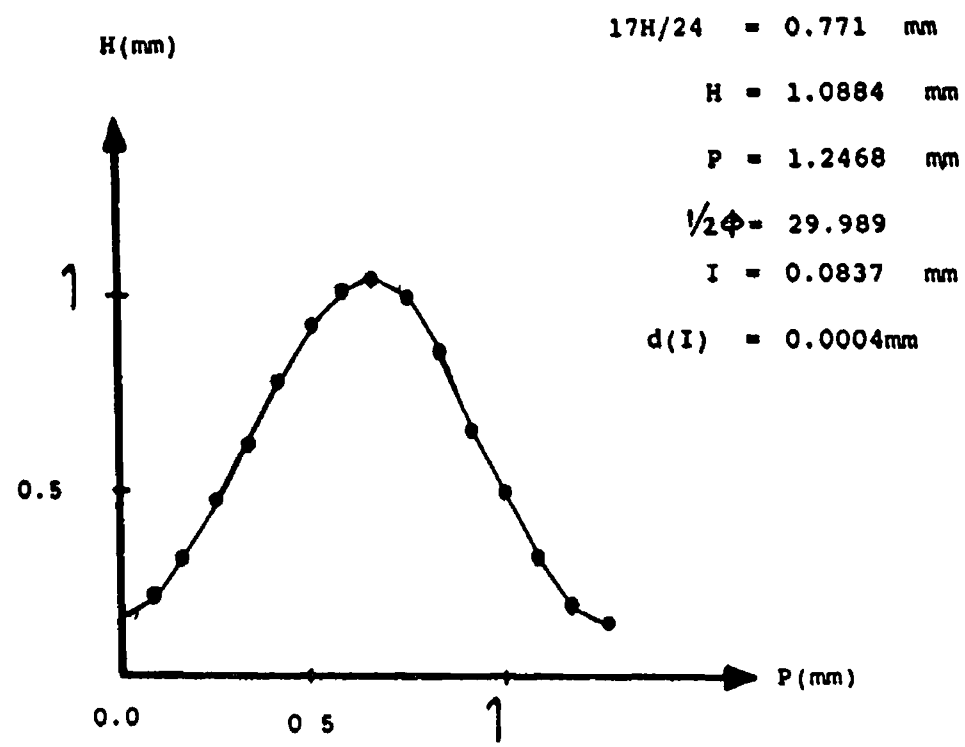


Figure (5-11)
FORM inspection of
M8, velocity 0.83 mm/sec

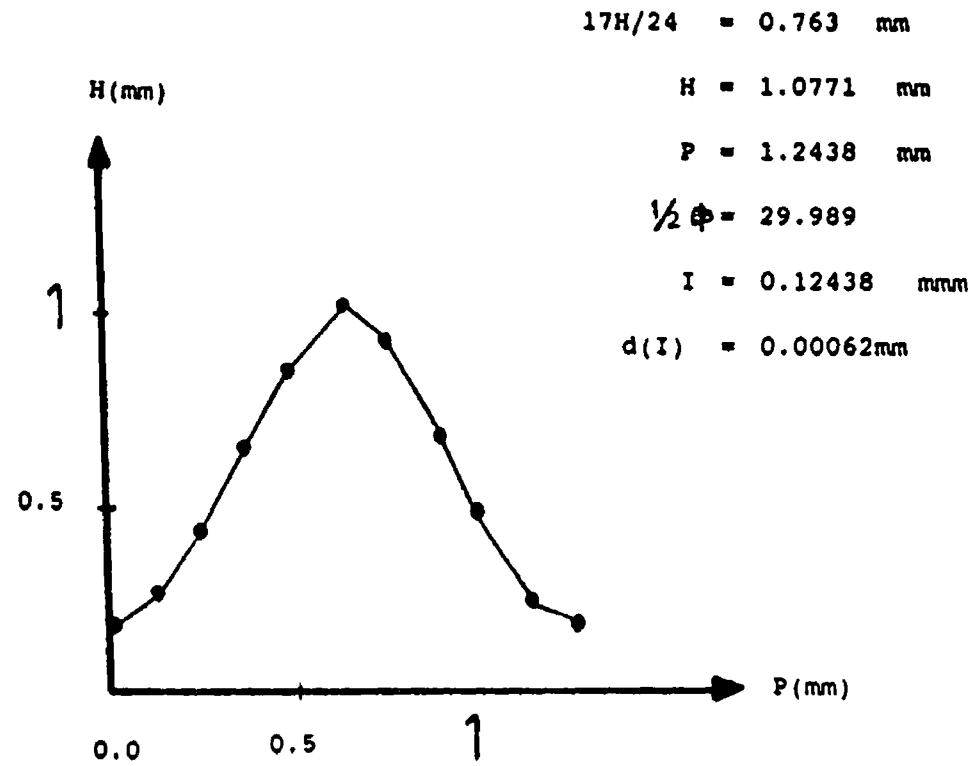


Figure (5-12)
FORM inspection of
M8, velocity 1.25 mm/sec

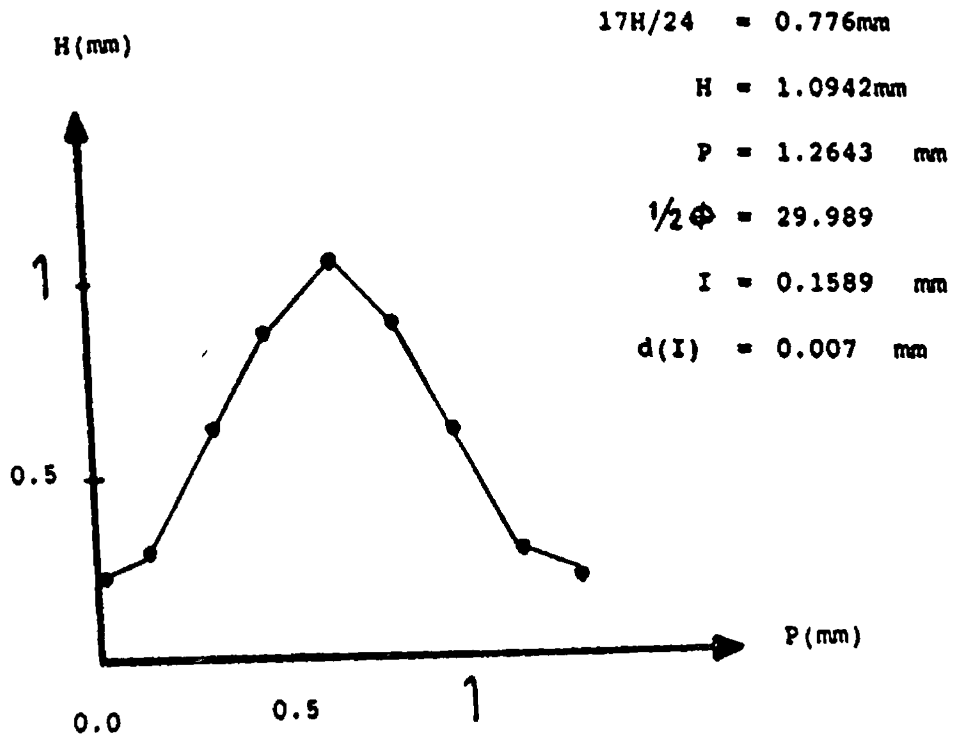


Figure (5-13)
FORM inspection of
M8, velocity 1.66 mm/sec

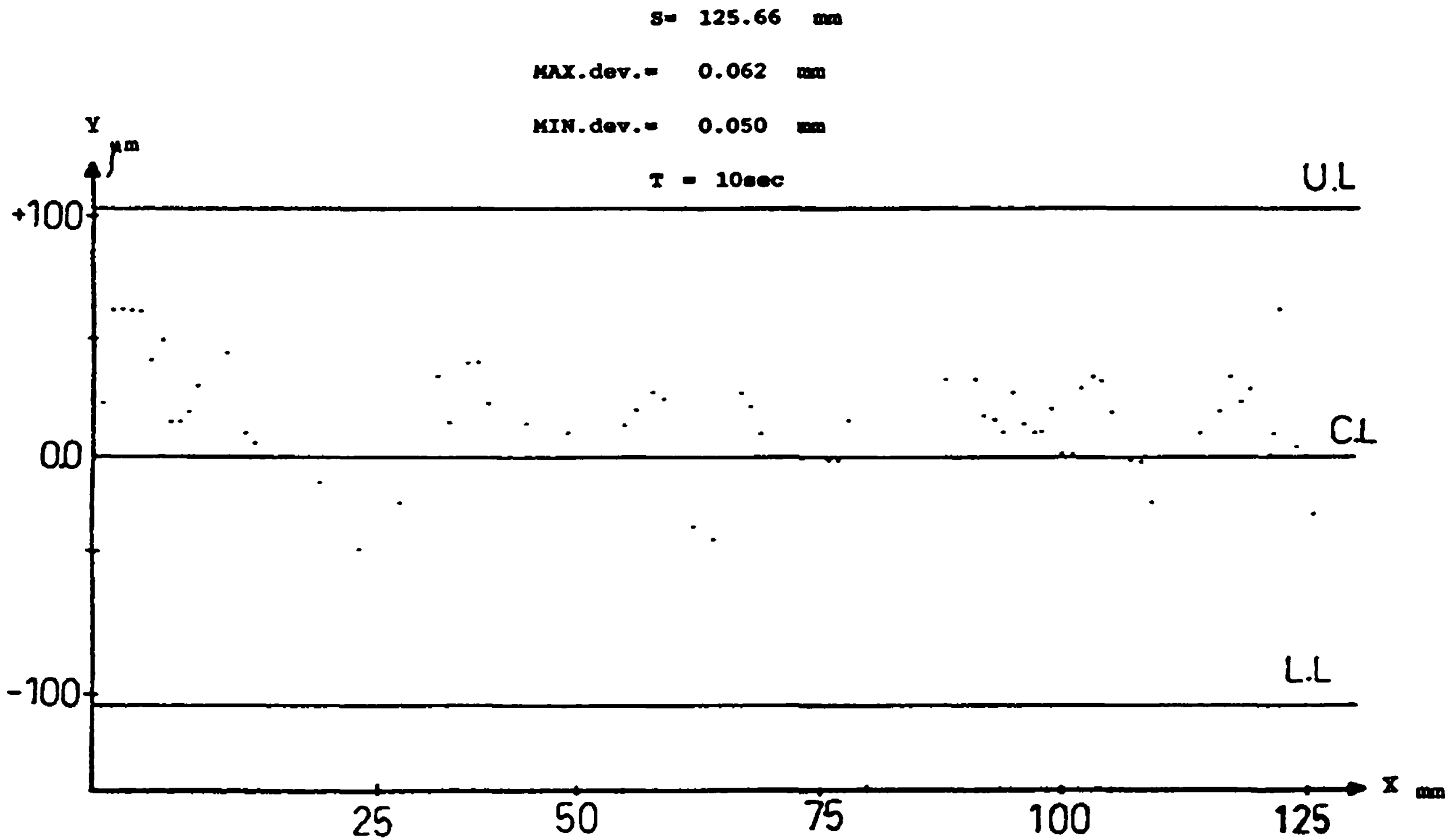


Figure (5-14)
HElIX inspection of
M8, five reolution, w=2.84 rad/sec

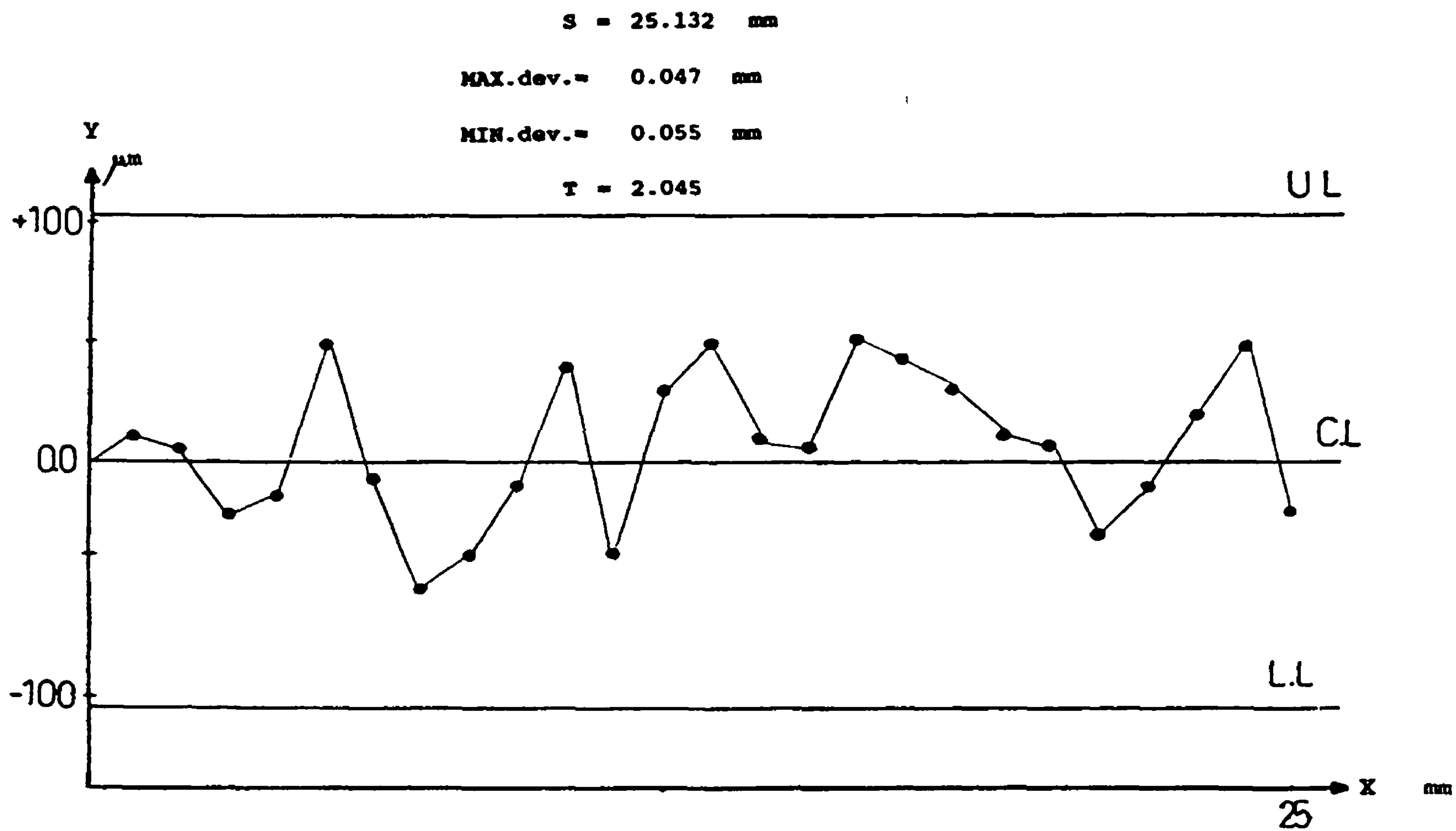
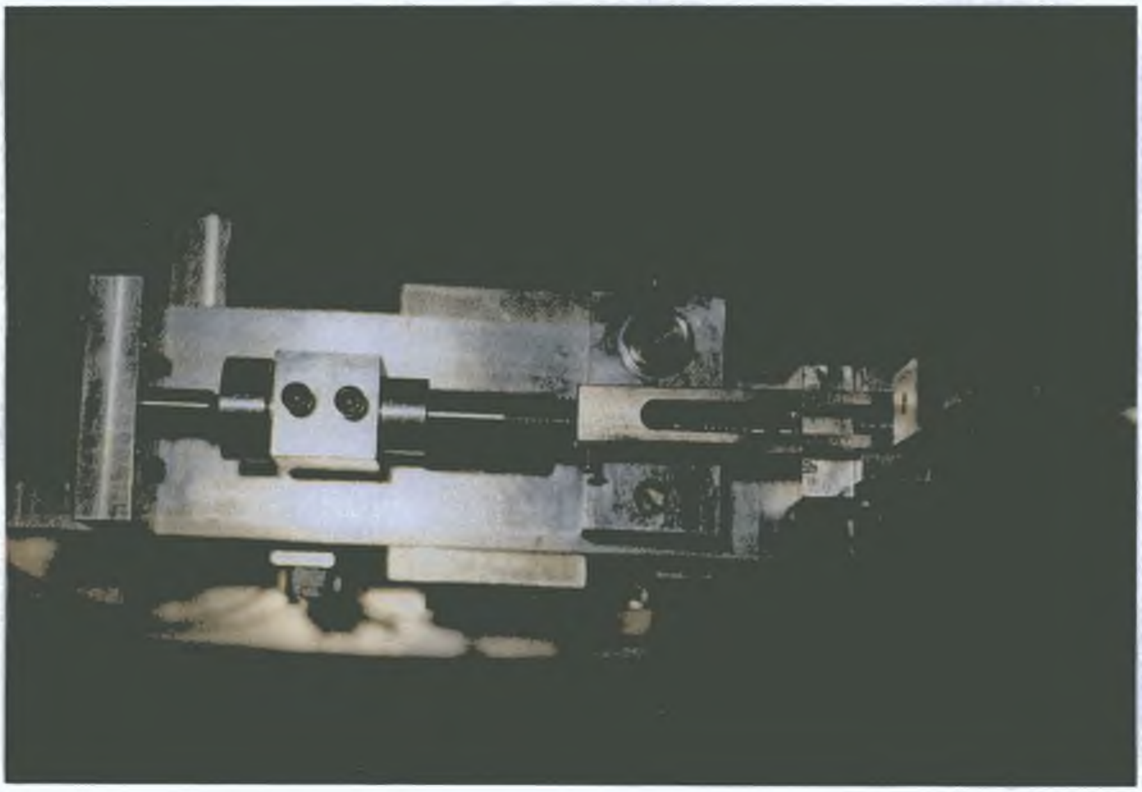


Figure (5-15)
HILEX inspection of
M8, one revolution, W=2.84 rad/sec



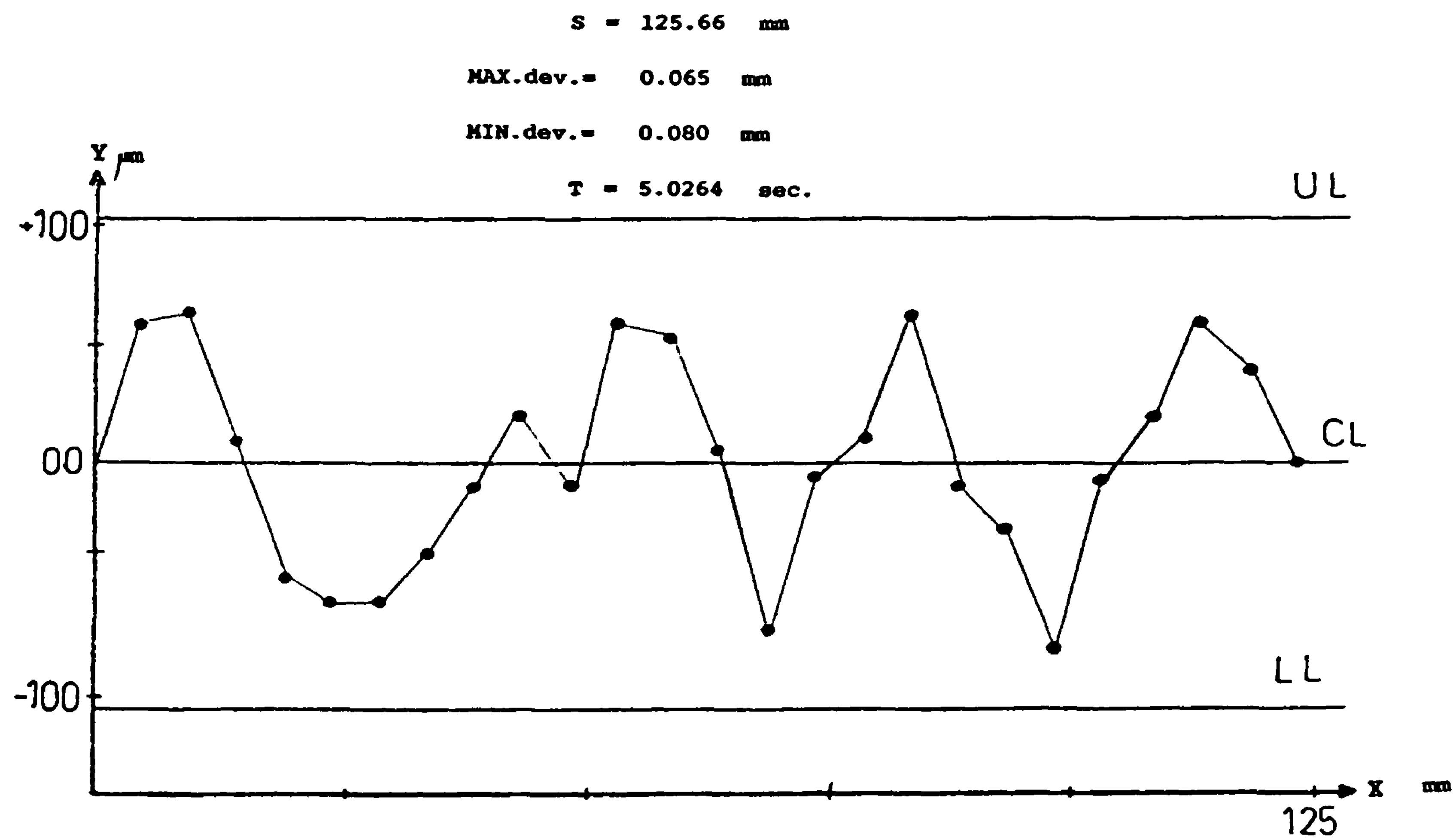


Figure (5-16)
HELIX inspection of
M8, five revolution, w=6.25 rad/sec

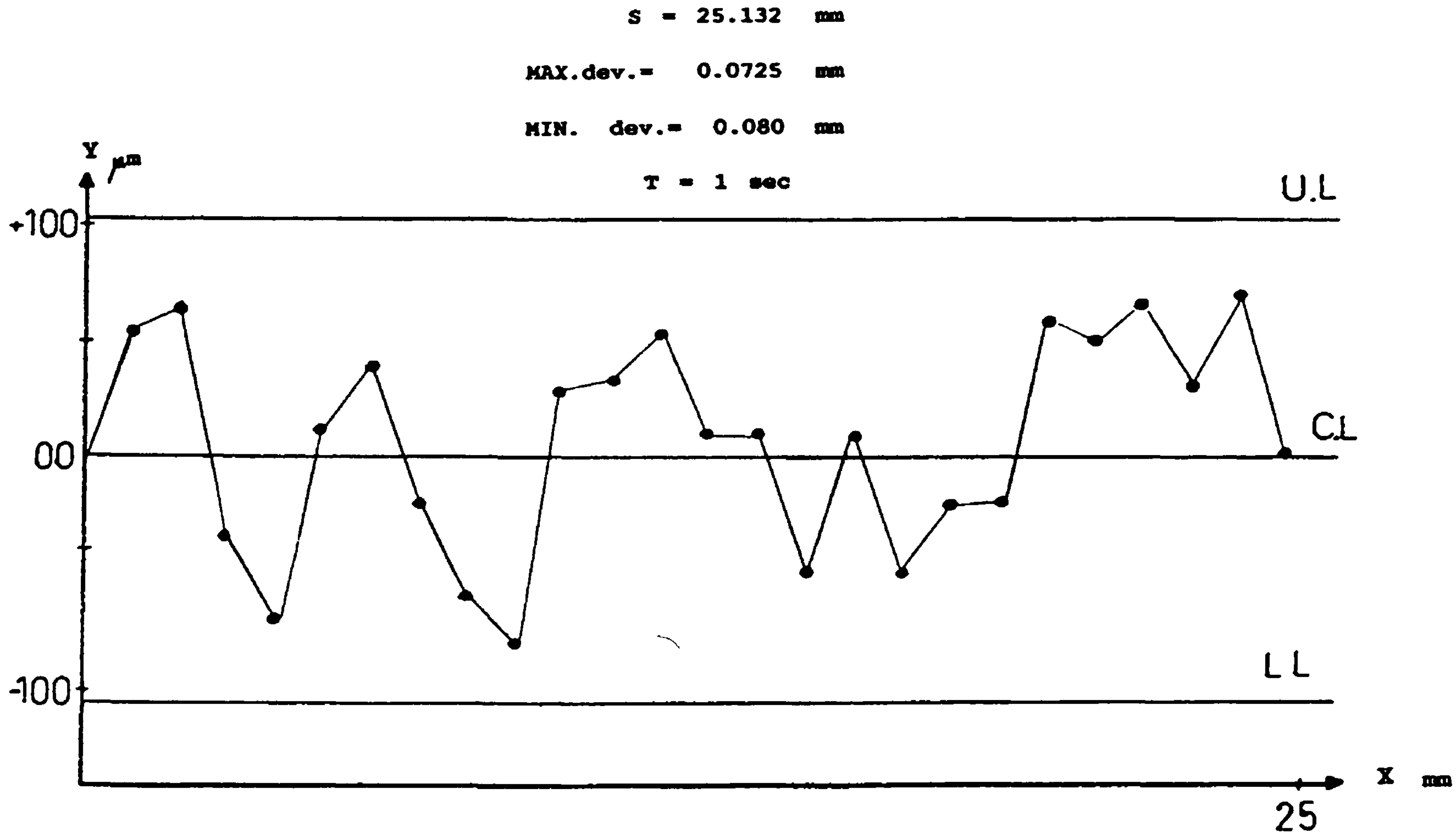


Figure (5-17)
HELIX inspection of
M8, one revolution, w=6.25 rad/sec

inspect the form of M8 these are: (0 5, 0 83, 1.25, 1 66 and 2) mm/sec In order to perform the helix path inspection of this size, we used three different an angular velocities these are consequently: (1 42, 2 5 and 6.25) rad/sec.

5-6-3-1 Form inspections

Figure (5-18), illustrates the result form of using a linear velocity to slow equal to 0.5 mm/sec., where the result of using the slow velocity equal to 0 83 mm/sec is shown on figure (5-19).
The medium velocity equal to 1 25 mm/sec , gives the form shown on figure (5-20). High and the very high velocity give the results which are represented on figures (5-21) and (5-22) respectively

5-6-3-2 Helix path inspections

Figure (5-23), shows the result of using an angular velocity equal to W_1= 1 42 rad/sec , and for five threads, the same velocity was used just for one thread and it gave the result shown on figure (5-24).
Another angular velocity used for the same bolt equal to 2 84 rad/sec., and it gave the form which is given on figure (5-25) for five thread and the result shown on figure (5-26) for one thread. The maximum angular velocity used to inspect the helix path of this size of thread was equal to W_3 =6 25 rad/sec The result is shown

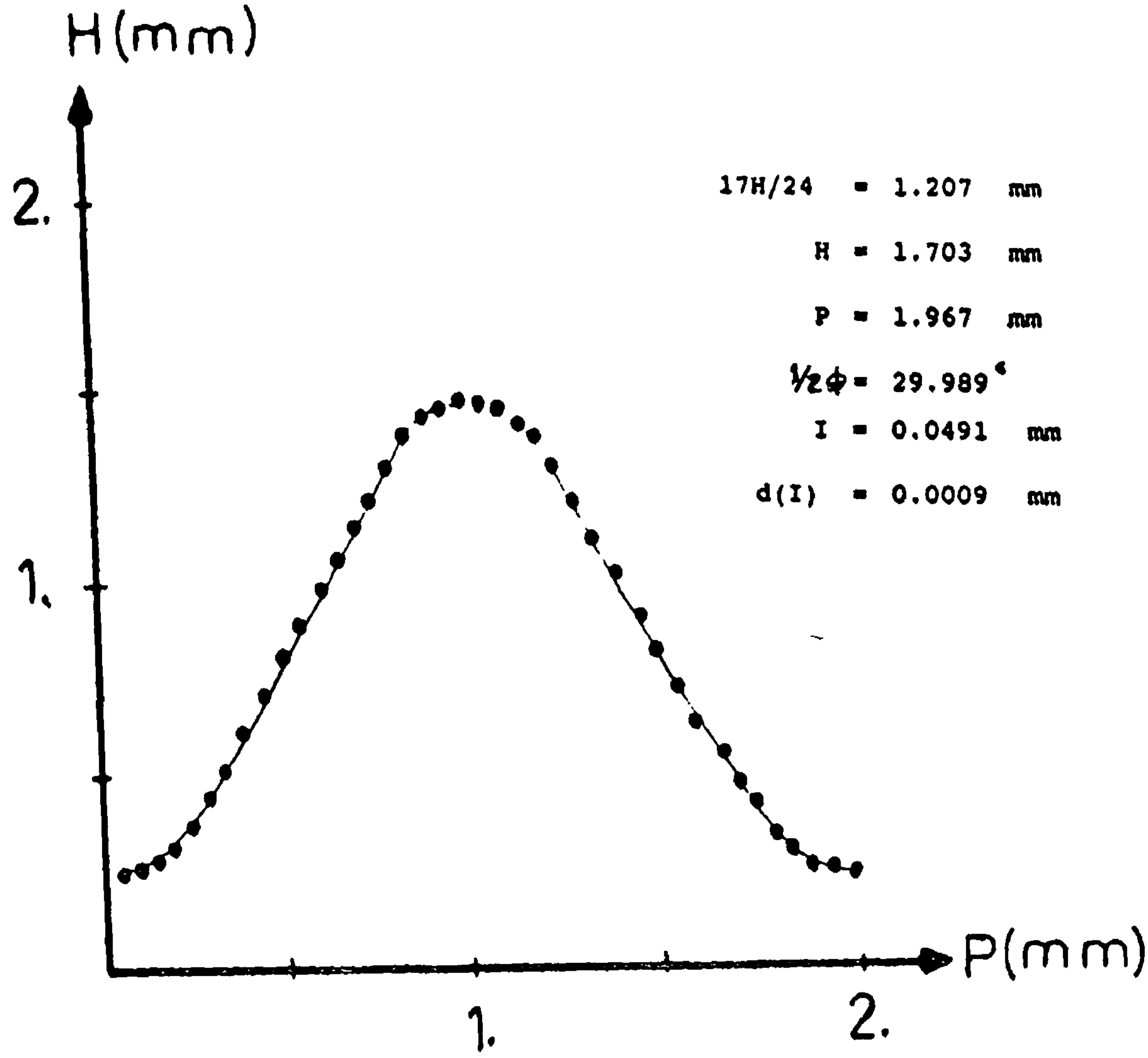


Figure (5-18)
FORM inspection of
M16, velocity 0.5 mm/sec

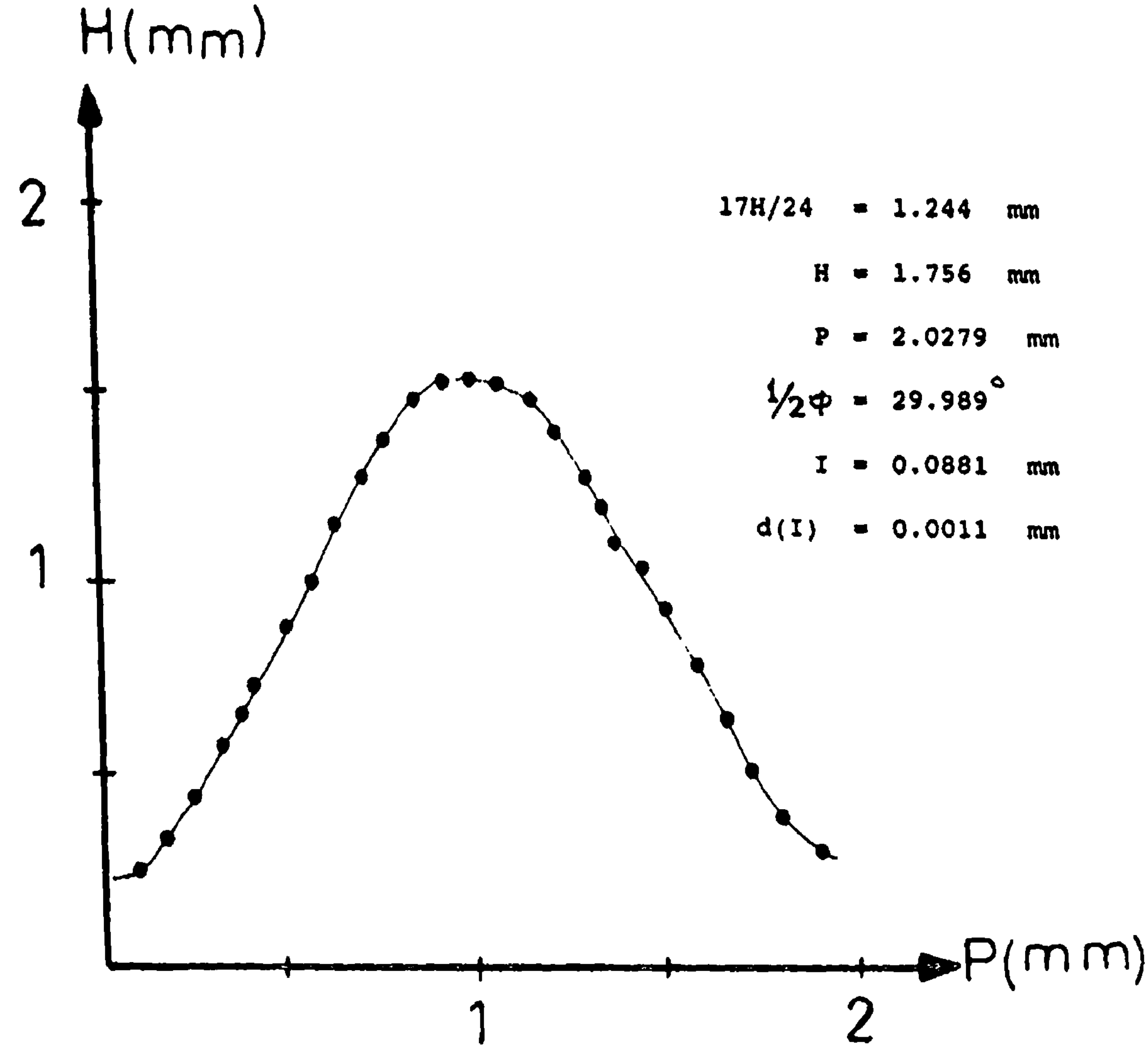


Figure (5-19)
FORM inspection of
M16, velocity 0.83 mm/sec

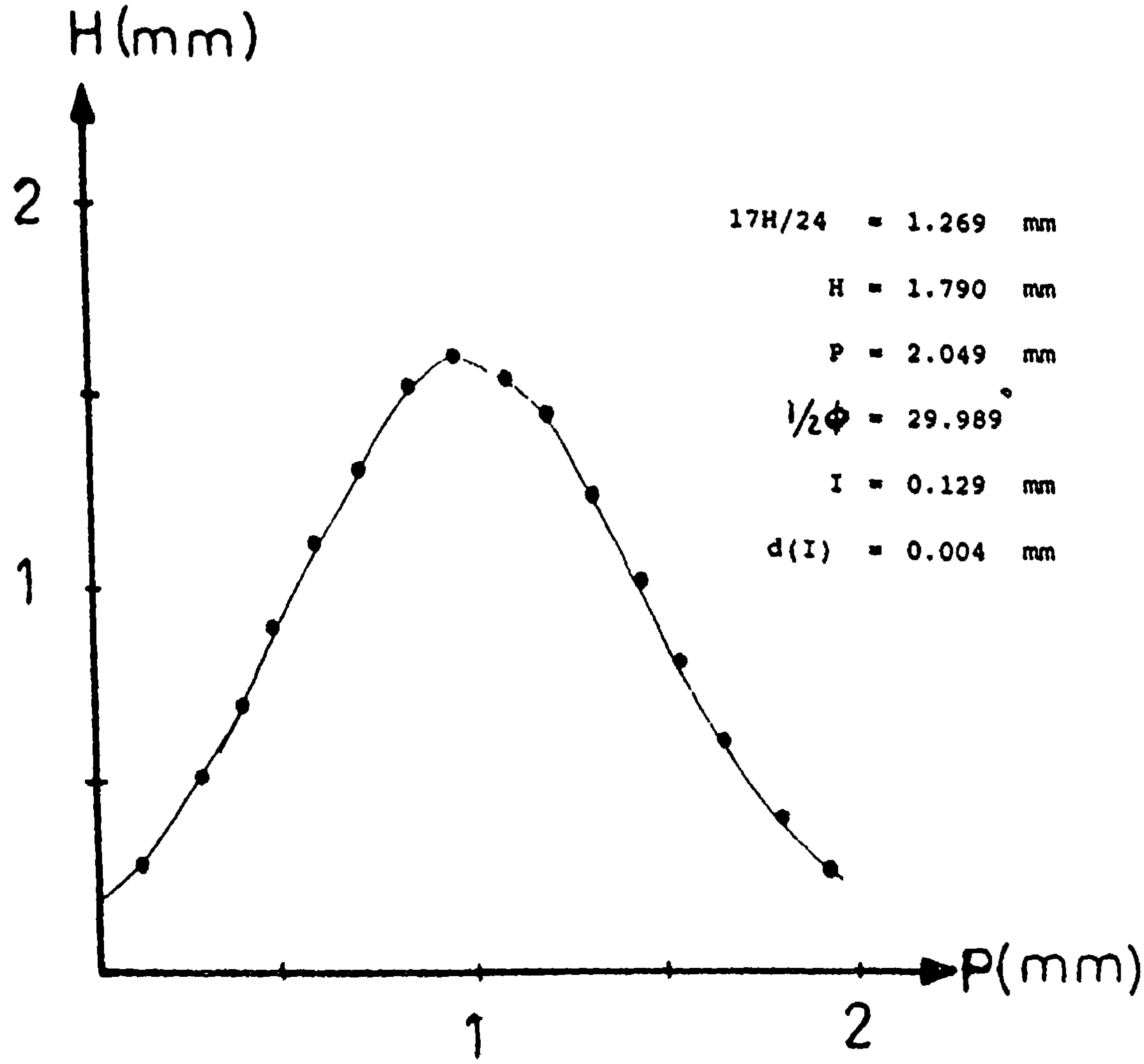


Figure (5-20)
FORM inspection of
M16, velocity 1.25 mm/sec

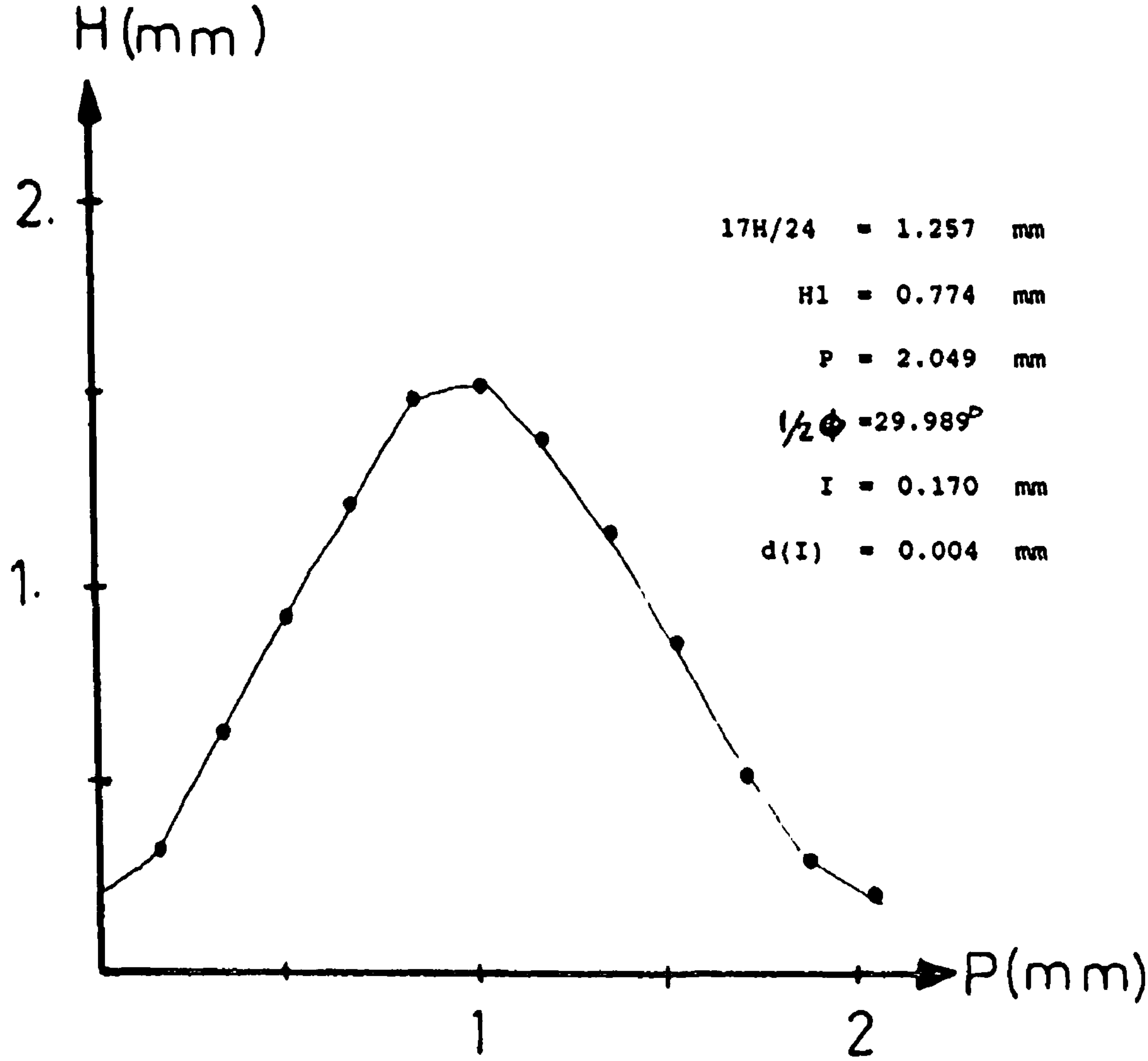


Figure (5-21)
FORM inspection of
M16, velocity 1.66 mm/sec

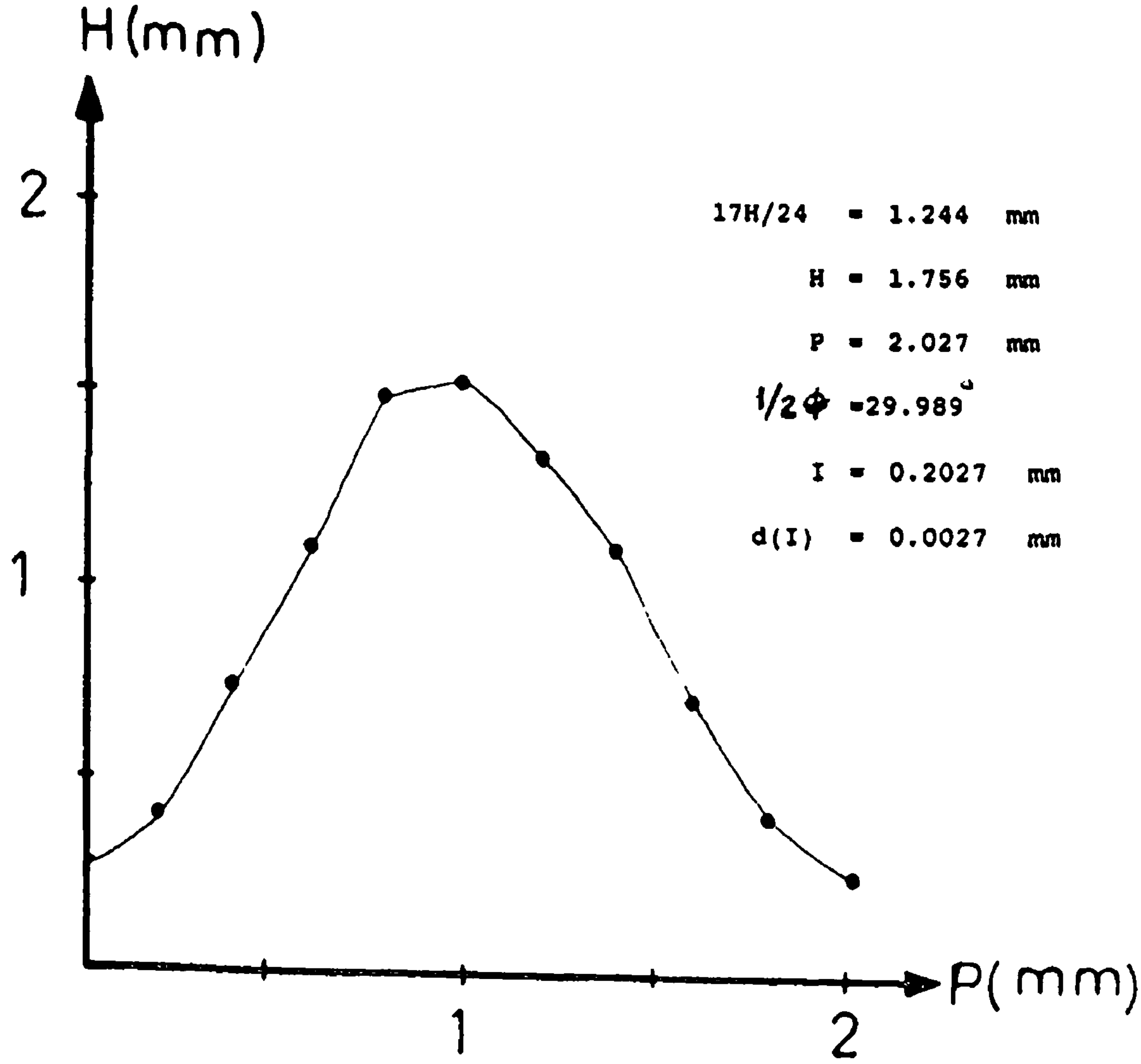


Figure (5-22)
FORM inspection of
M16, velocity 2 mm/sec

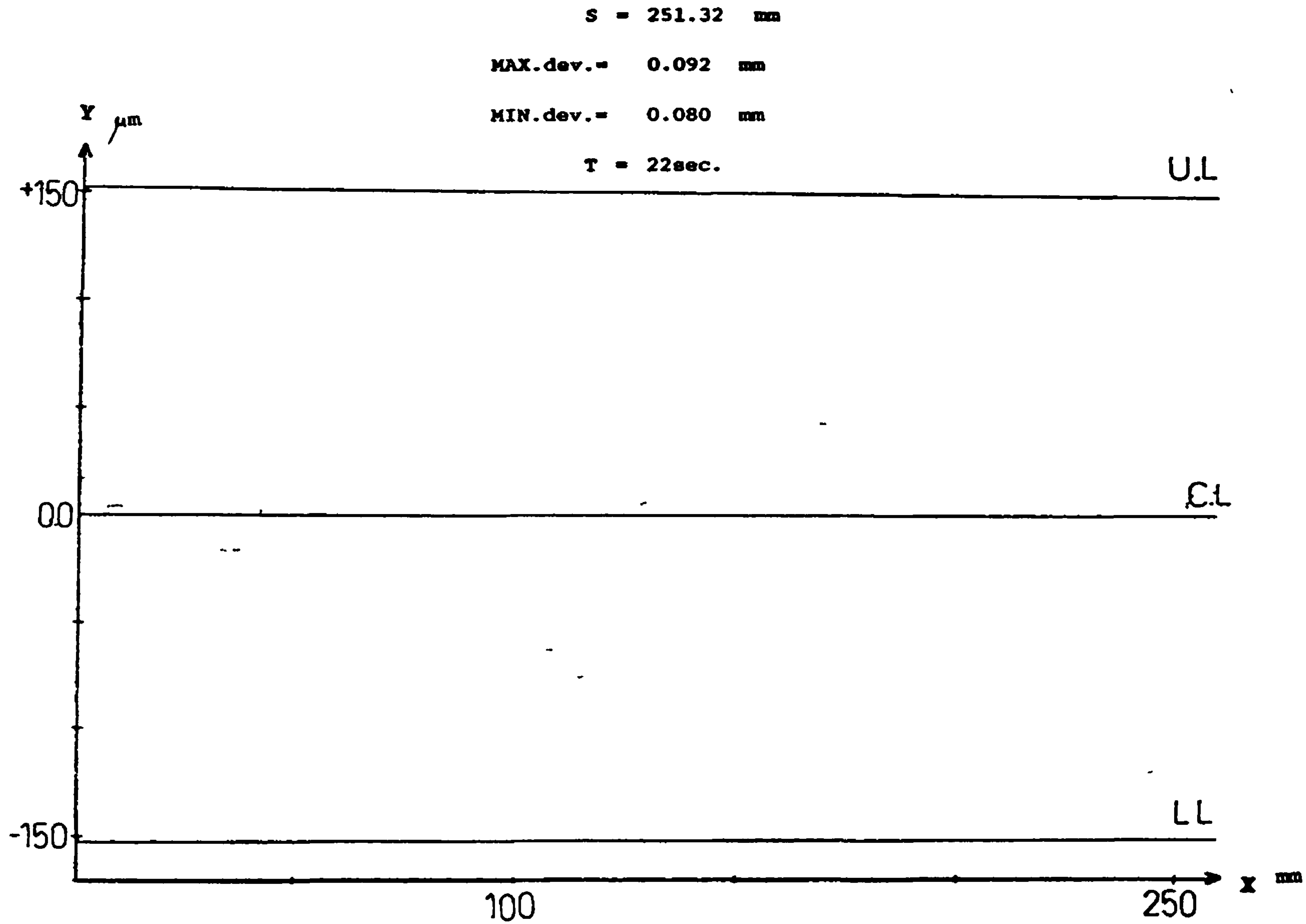


Figure (5-23)
HELIX inspectın of M16
five revolutıon, w=1.42 rad/sec

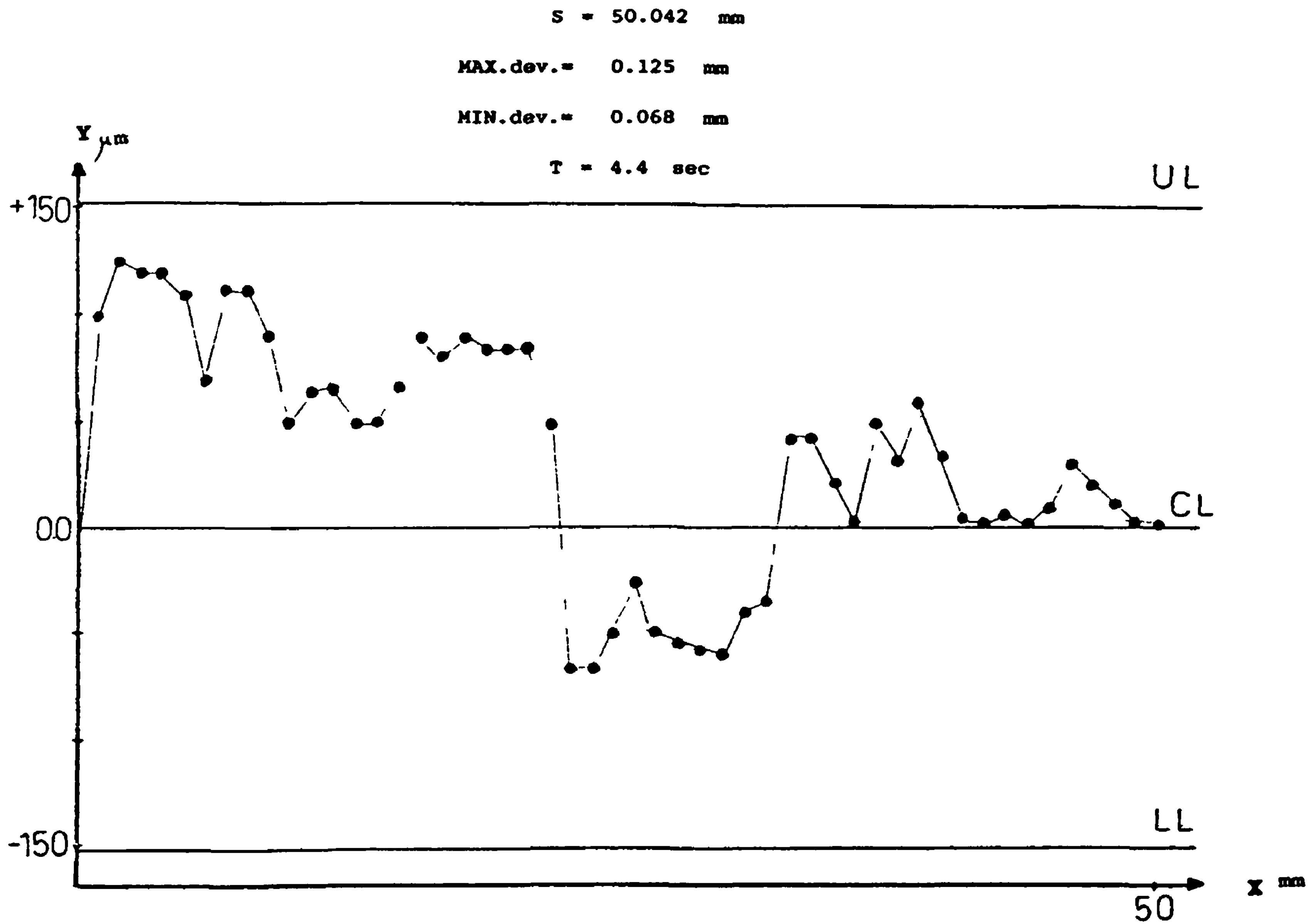


Figure (5-24)
HELIX inspection of M16
one revolution, W=1.42 rad/sec

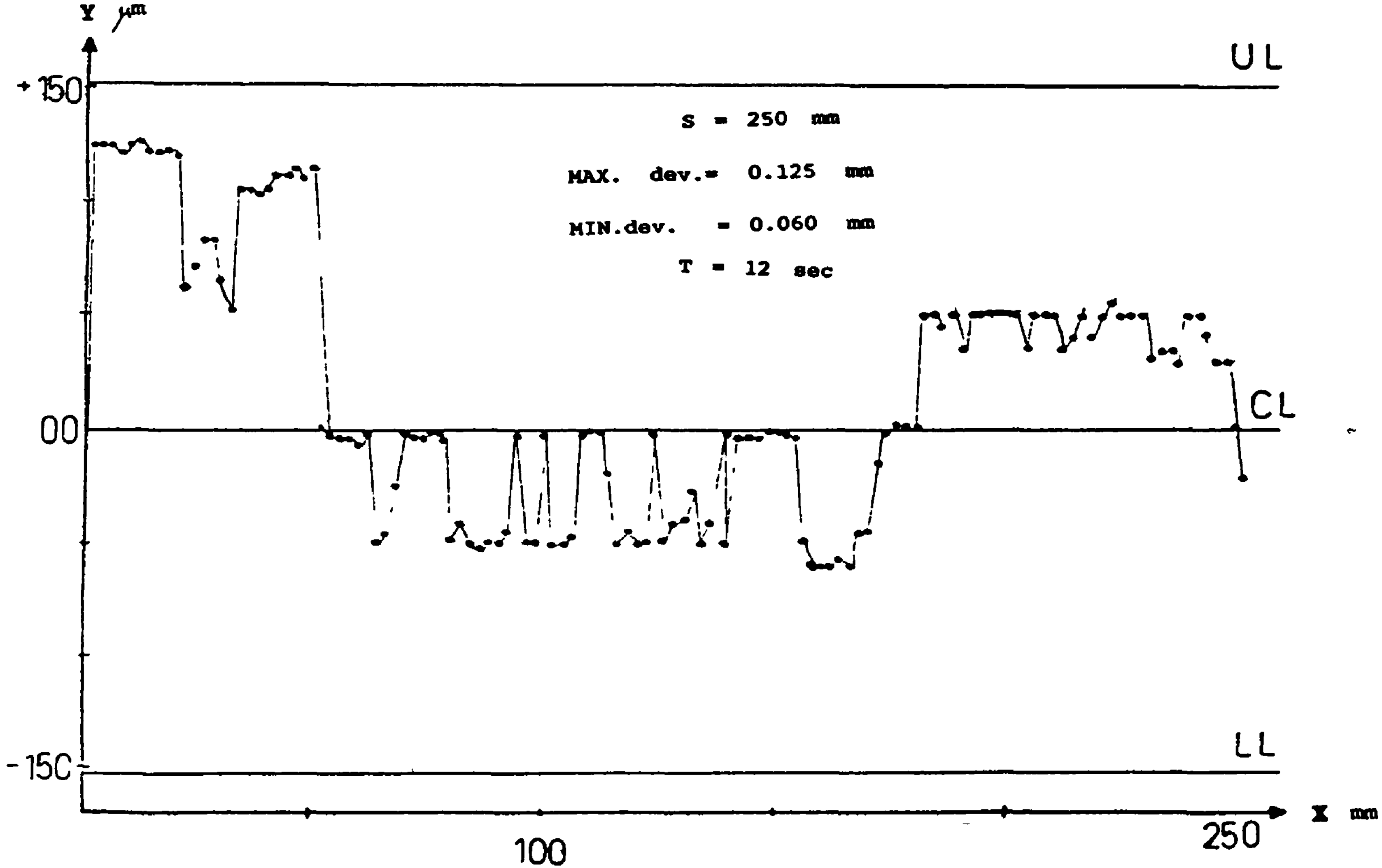


Figure (5-25)
HELIX inspection of M16
five revolution, w=2.84 rad/sec

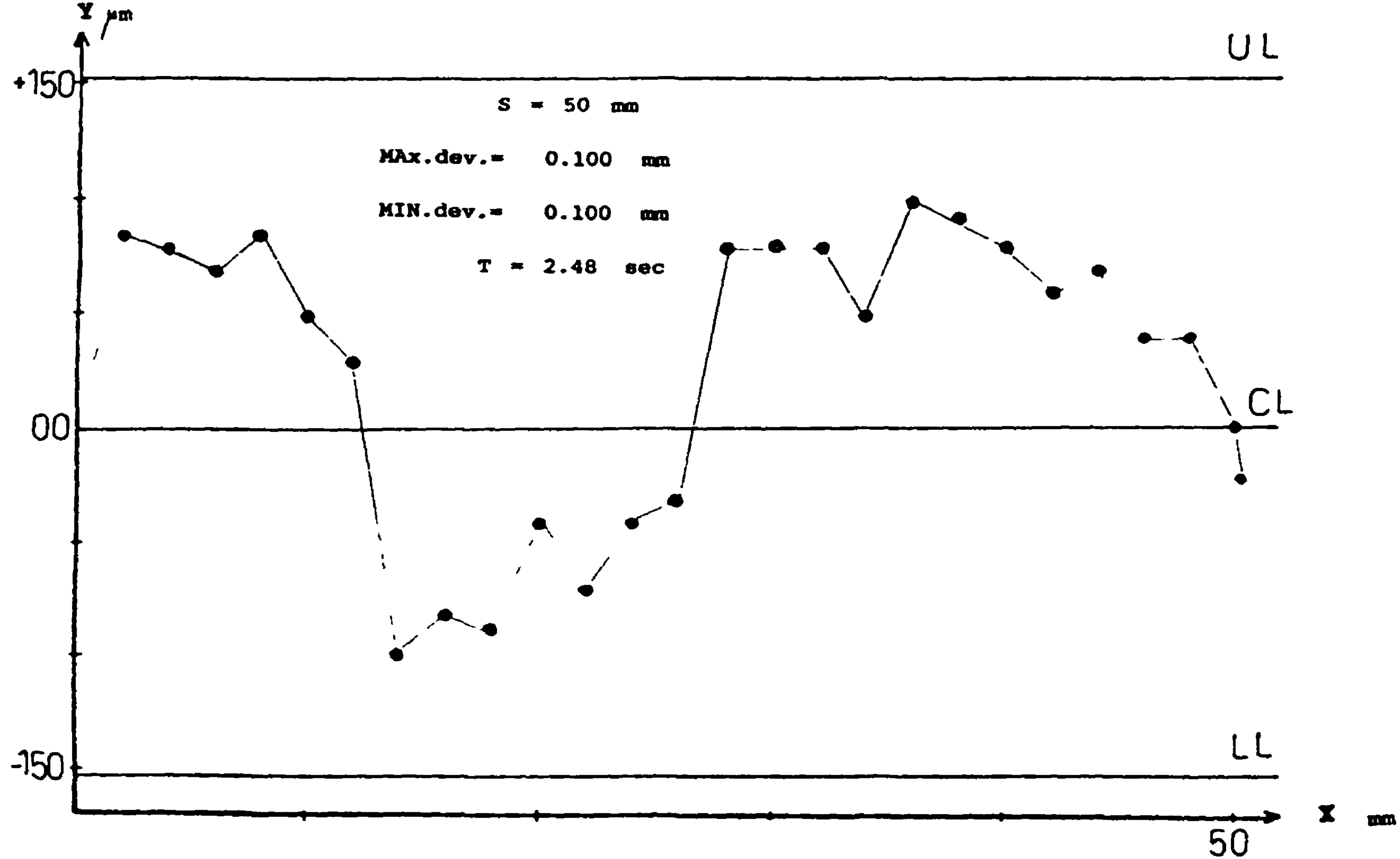


Figure (5-26)
HELIX inspection of M16
one revolution, w=2.84 rad/sec

on figure (5-27) for five threads.

5-6-3-3 Artificial defect on the crest of M16

An artificial defect was made on the crest of the thread Using three different velocities this defect detected, figure (5-28), shows the form obtained at 0 83 mm/sec linear velocity

5-6-3-4 Artificial defect on the helix path of M16

Also another type of defect was done at the root, using two different angular velocities this defect detected

Figure (5-29), shows the variation of the two velocities

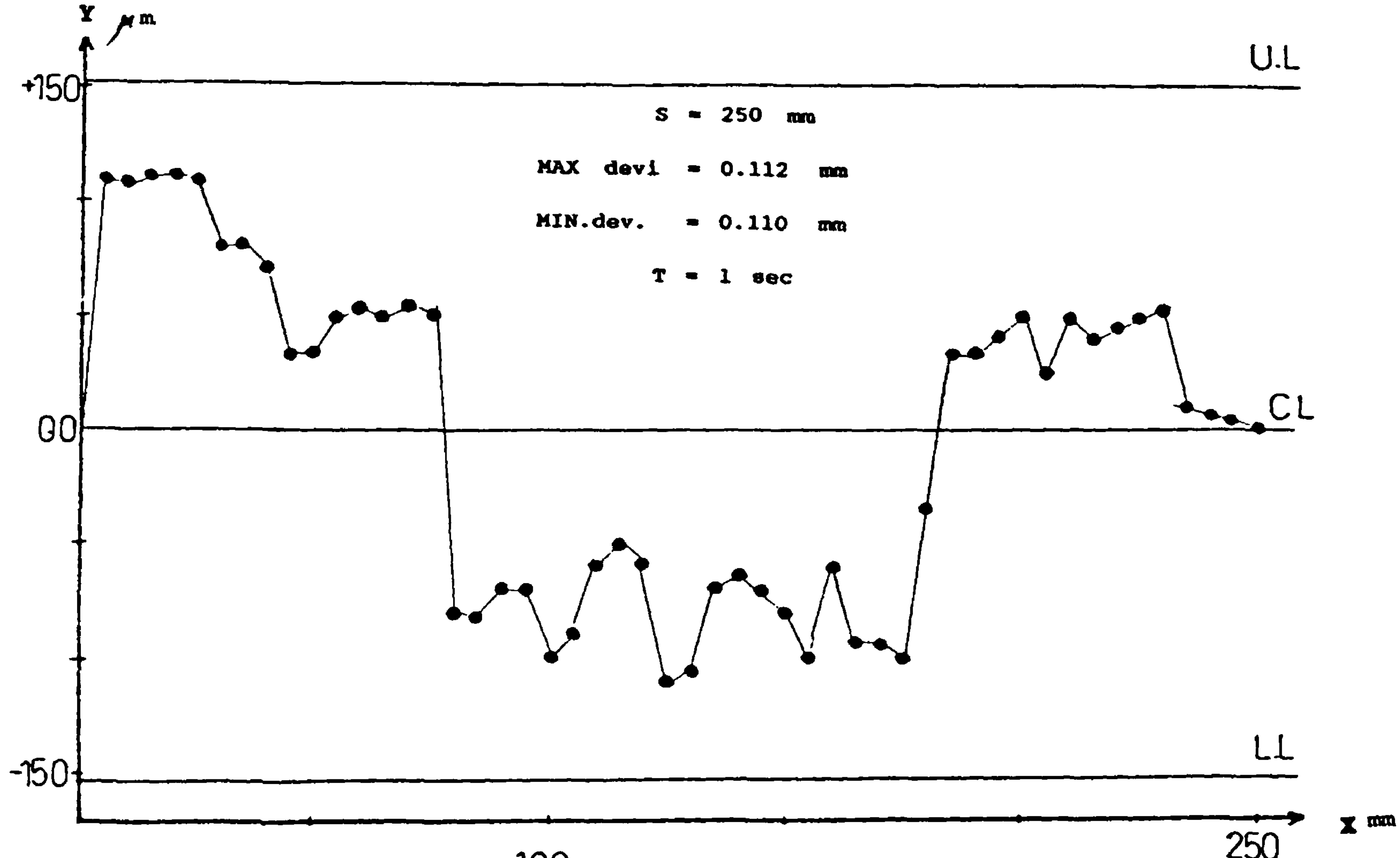


Figure (5-27)
HELIX inspection of M16
five revolution, w=6.25 rad/sec

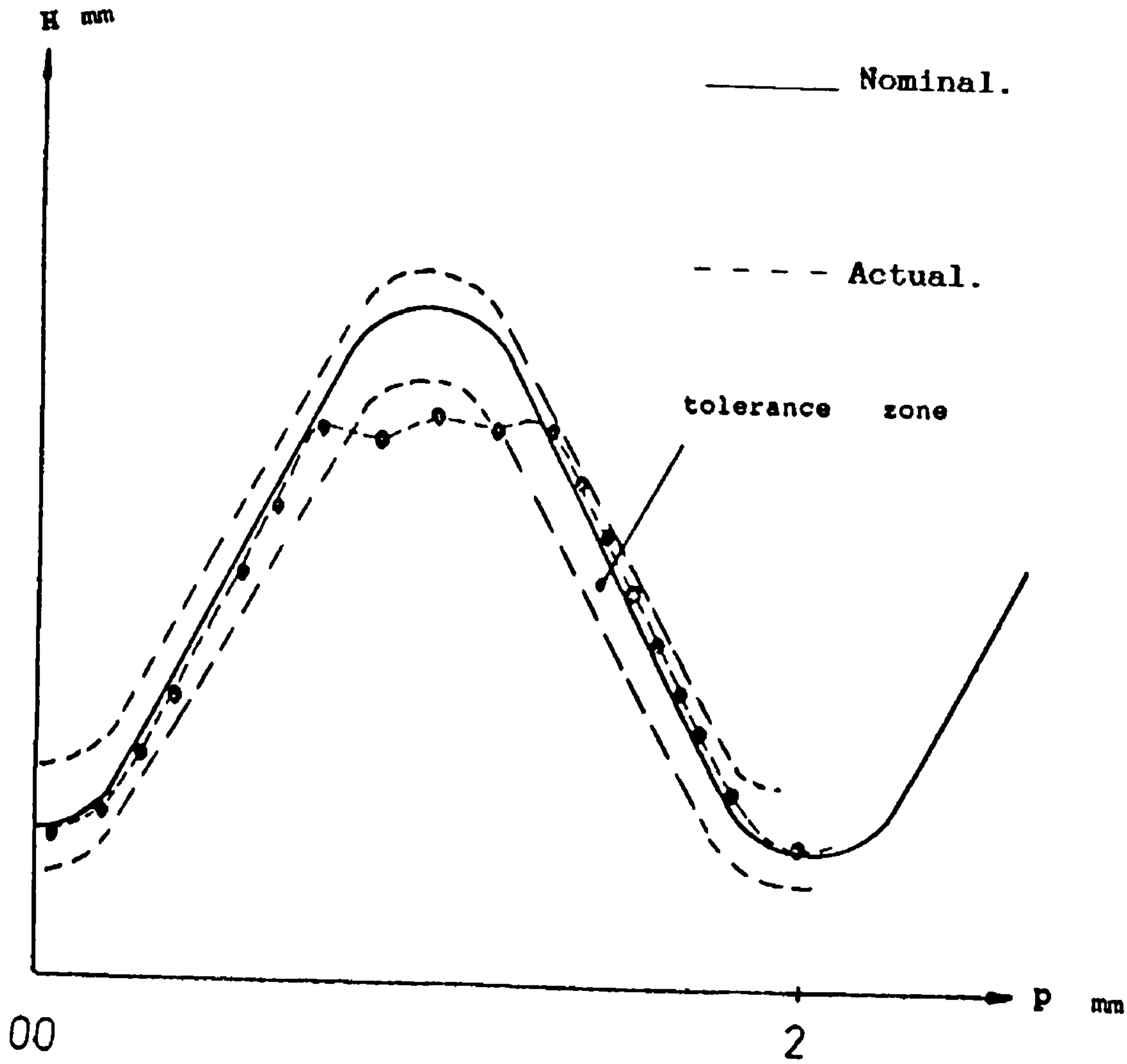


figure (5-28)

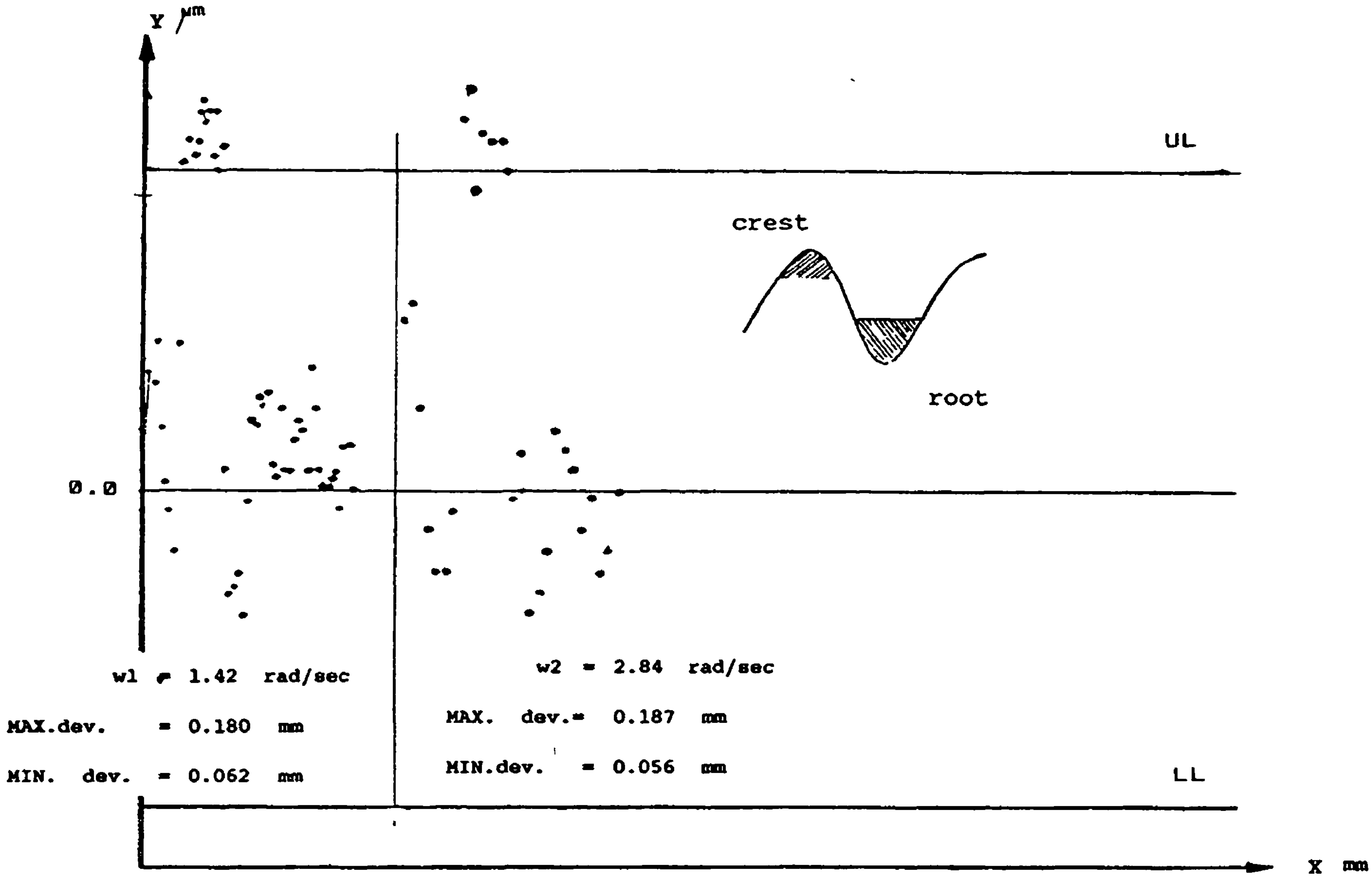

Y µm
UL
crest
root
0.0
w1 = 1.42 rad/sec
MAX.dev. = 0.180 mm
MIN. dev. = 0.062 mm
w2 = 2.84 rad/sec
MAX. dev.= 0.187 mm
MIN.dev. = 0.056 mm
LL
X mm

figure (5-29)

CHAPTER SIX

6 - RESULTS & DISCUSSION

6-1 Discussion of the experimental results

The experimental results shown in chapter five will be discussed and analyzed in this chapter, in order to find out the following.

(a)- The factors which effect the accuracy of the system

(b)- The behaviour of the stylus movement due to the different velocities

(c)- To select the optimum velocity required for each bolt size

(d)- To find the relationship between the degree of accuracy and the different parameters of the bolt (pitch, depth of the thread, etc)

Therefore, the discussion will be divided under the following sections

(1)- The form inspection results.

(2)- The helix path inspection results

(3)- The artificial defects (form, helix path)

The previous test was repeated three times for the profile form cases While the helix path test was repeated five times

6-2 The form inspection results

A very slow, slow, medium, high, and a very high velocities were provided in order to perform the profile form of the bolts M6, M8 and M16 Therefore each bolt size test will be discussed separately

6-2-1 The result of the bolt M6

This bolt was manufactured by rolling Its theoretical profile form is shown in figure (6-1), This is based on the BS 3643, part one and two of the ISO metric screw threads

The very slow, velocity 0 5 mm/sec firstly was provided in order to perform the profile form of this bolt size The result of this, were compared with the BS 3643, and they were within the specified tolerance zones

While the actual profile form was developed depending on the previous mentioned results Then, the actual profile form was superimposed on the theoretical one for comparison The comparison, shows that the actual profile form is in a good agreement with the theoretical one This may be due the high accuracy provided due to the very slow motion

The difference between the theoretical and the actual pitch is 0 0114 mm And the difference between the

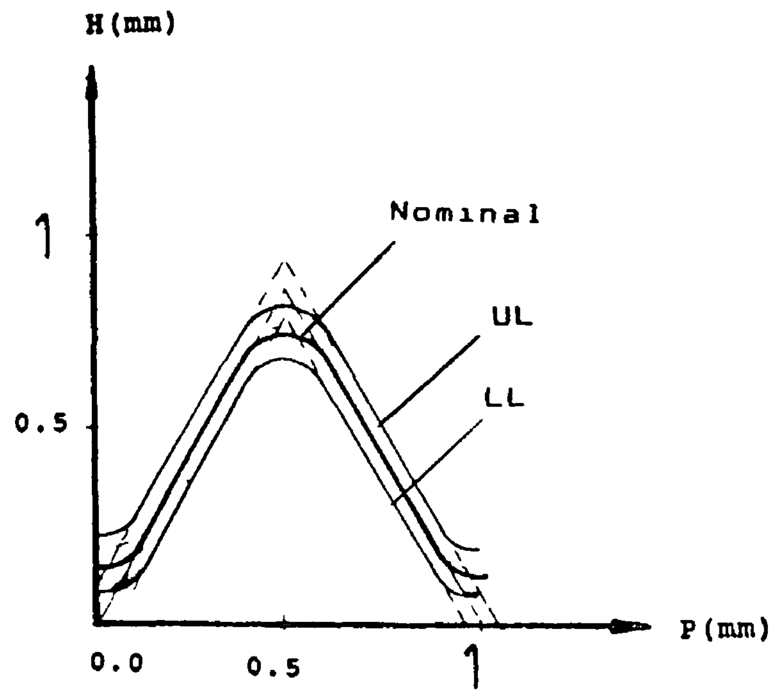


Figure (6-1)
Theoretical profile form of M6

theoretical and the actual depths is 0.007 mm. Therefore these differences can not be distinguished on the actual profile form as shown in figure (6-2)

Also, the difference between the theoretical and actual increments is 0 0006 mm, and this is a very small value. This difference explains the good agreement between the theoretical and actual profile form Finally, the stable running of the stylus is another reason which explains the good accuracy

In order to reduce the inspection time of the operational cycle, a slow velocity 0 83 mm/sec was provided The result of this test were compared with the **BS 3643** and they were within the specified tolerance zones

Also the differences between the results of this test and the previous one is very small, if they are compared to each other

However, the actual profile form was developed according to these results After that it was superimposed on the theoretical one for comparison The difference between the theoretical and actual pitch has been increased by 0 003 mm, compared with the previous one

Also, the difference between the theoretical and actual depth has been increased to 0 005 mm, compared with the previous one

The difference between the theoretical and actual increment, still very small and is equal to 0 0013 mm

Also, the stylus has a stable running due to this velocity Therefore the actual profile form has, also a good agreement with the theoretical one as shown in

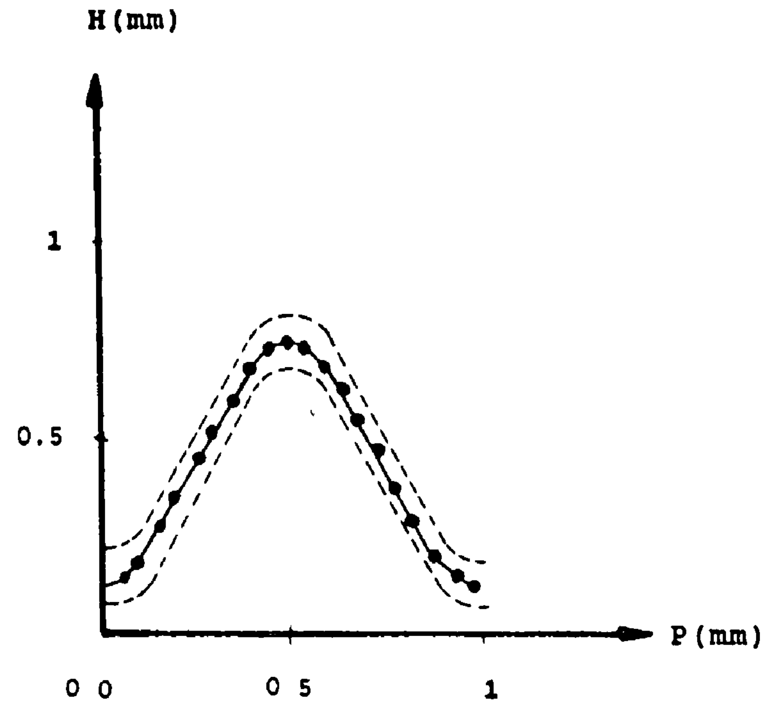


Figure (6-2)

figure (6-3)

In order to reduce further the time of the operational cycle, the previous velocity (0 83 mm/sec) was increased to 1 25 mm/sec The results of this test were compared with the standard one in the **BS 3643,** and they were within the specified tolerance zones

Figure (6-4), illustrates the actual profile form which is superimposed on the theoretical one The comparison shows the noticeable deformation of the actual profile form at the crest and the root of the tooth This is due to the increase in the velocity by 0 42 mm/sec, compared with the slow one And by 0 75 mm/sec, compared with the very slow velocity (0.5 mm/sec) This also affects the response time of the linear variable differential transformer (LVDT)

Also the stylus due to this velocity does not have the same stable running as in the two previous tests While the difference between the theoretical and the actual increment was increased from 0 0006 mm due to the very slow velocity to 0 003 mm

However the results are good and the actual form is in good agreement with the theoretical one

Two different velocities, (1 66 and 2 mm/sec), also were used in order to reduce more and more the inspection time of the operational cycle Unfortunately the results due to these velocities were very changeable and they were out of range to be discussed or analyzed Therefore these velocities will not be used for this bolt size

Table (6-1), gives a summary for the different tests of

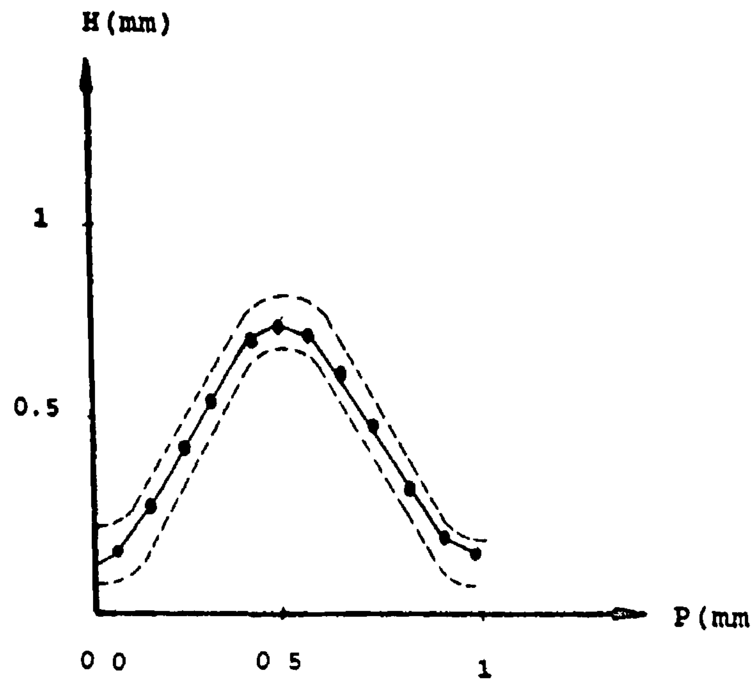


Figure (6-3)

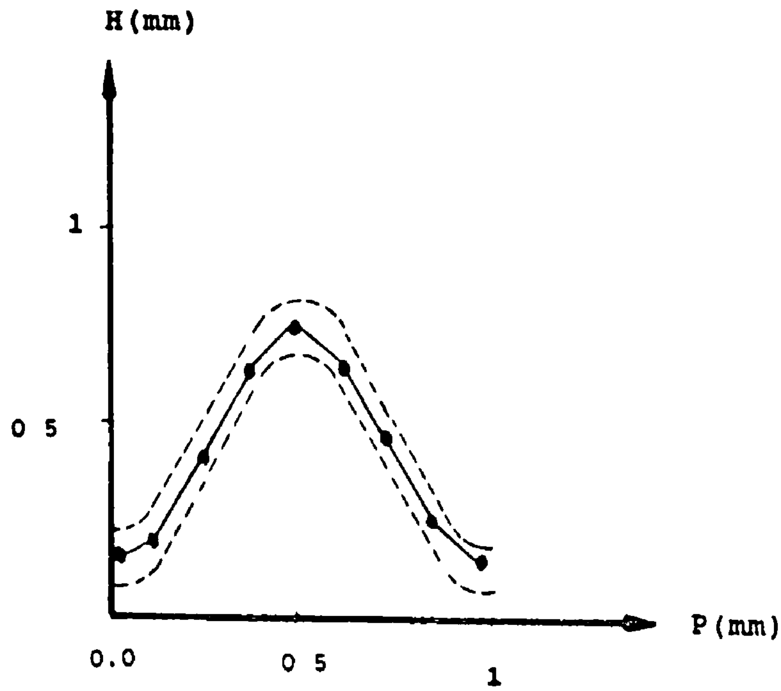


Figure (6-4)

Table (6-1)

ACTUAL

V	17H/24	H	P	.5 Φ	I
.5	.606	.865	.989	29.9	.0494
.83	.604	.853	.985	29.9	.0820
1.25	.601	.848	.980	29.9	.122
1.66	X	X	X	X	X
2	X	X	X	X	X

	d(17H/24)	d(H)	d(P)	d(Φ)	d(I)
1	.00744	.01	.011	39.6"	.0006
2	.00944	.013	.015	39.6"	.0013
3	.01244	.018	.02	39.6"	.003
4	X	X	X	X	X
5	X	X	X	X	X

Theoretical

t	17H/24	H	P	.5 Φ	I
2					.05
1.2					.083
.8	.613	.866	1	30	.125
X					X
X					X

this bolt size

In which a comparison was made between the theoretical parameters and the actual one However the following points can be obtained from this table

*(1)- **When** the velocity increases, the accuracy of the results decreases*

*(2)- **The** good agreement between the theoretical and actual profile form can be achieved due to the very slow and slow velocities for this bolt size*

*(3)- **The** medium velocity 1 25 mm/sec, can be provided where the time is very important and less accuracy is required*

6-2-2 The results of the bolt size M8

In order to discuss the different tests of this bolt, the previous procedure was adopted, also the same steps were be repeated subsequently

The theoretical profile form of this bolt size is shown in figure (6-5) While the actual profile forms, which were superimposed on the theoretical one for comparison, are given consecutively in figures (6-6), (6-7) and (6-8) Their results were within the specified tolerance zones Also, each one of the actual profile form has a good agreement with the theoretical one The reasons are the same as they are mentioned previously, in order to explain cases, one and two of the bolt size M6 Also, a

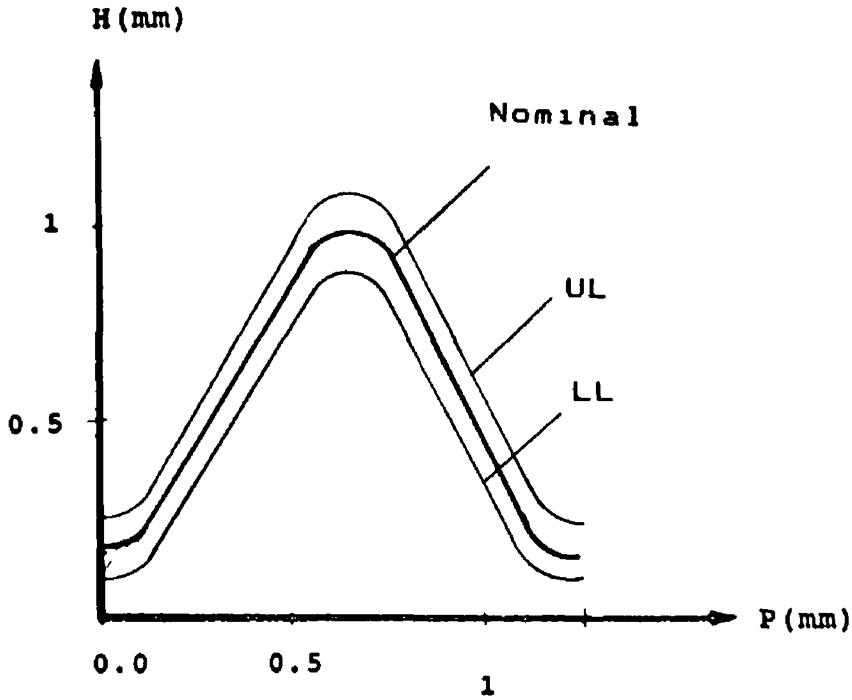


Figure (6-5)
The theoretical form of M8

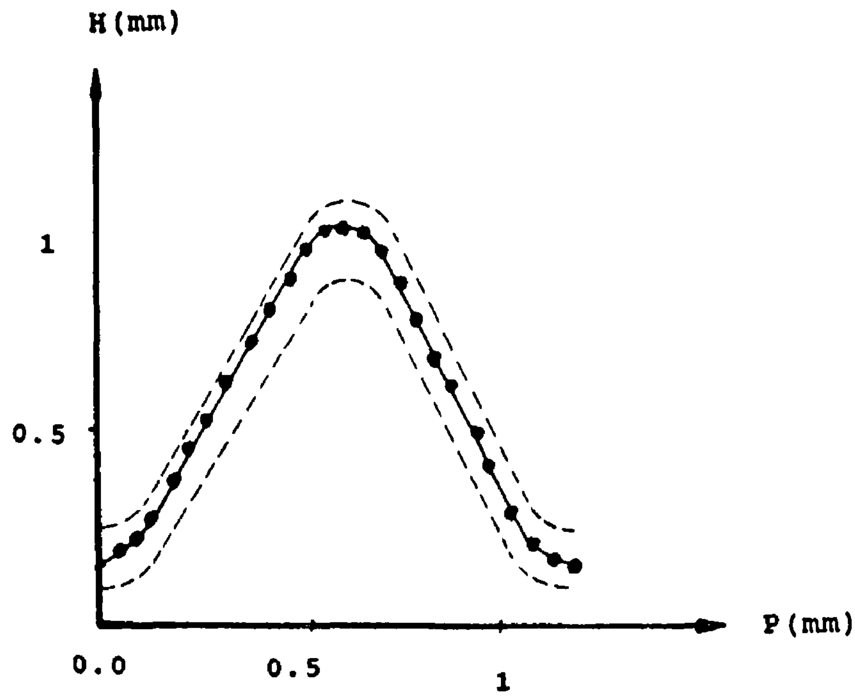


Figure (6-6)

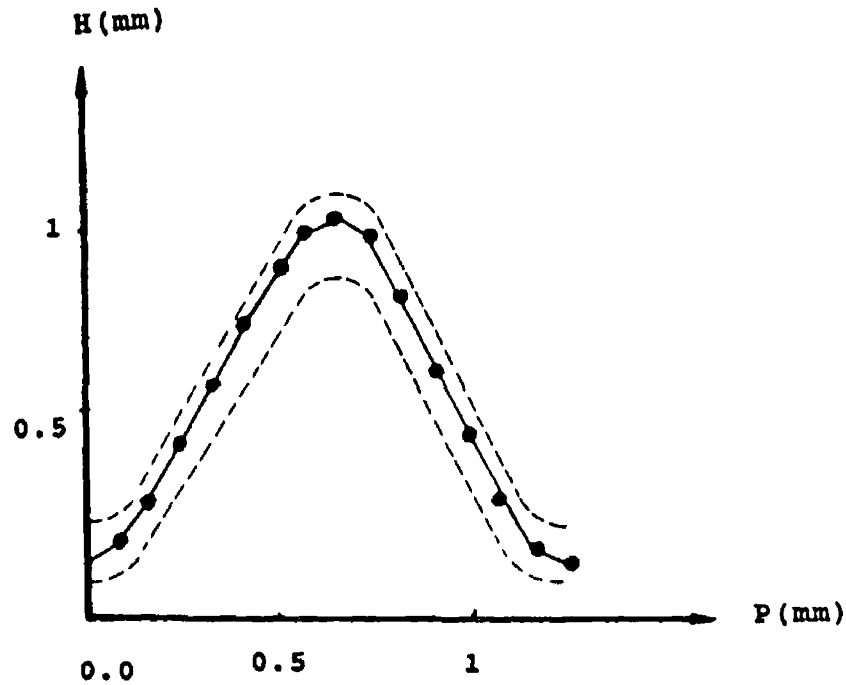


Figure (6-7)

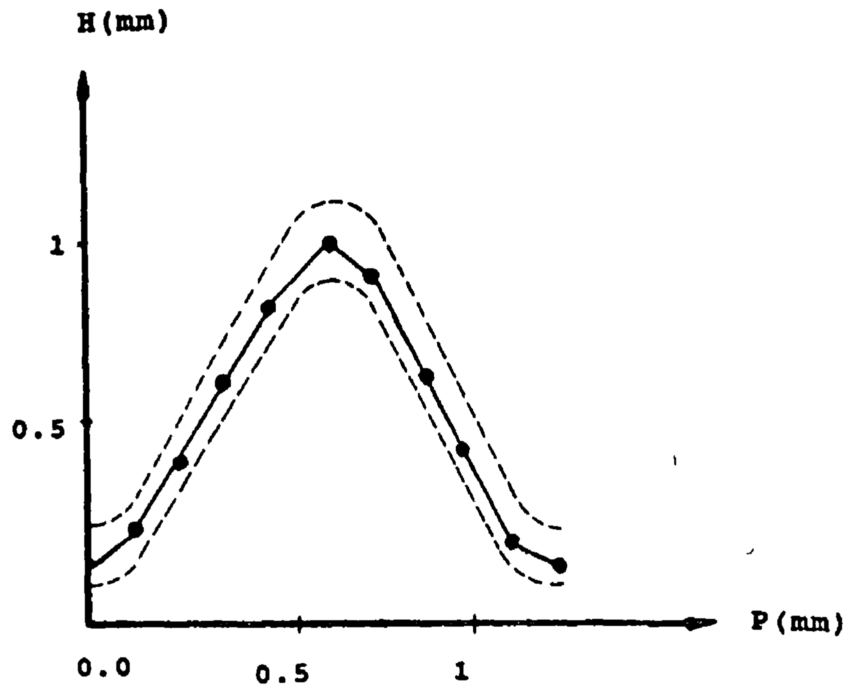


Figure (6-8)

high velocity of 1.66 mm/sec was used in a new attempt to reduce the inspection time of the operational cycle. The results were compared with the reference one and they were within the specified tolerance zones Figure (6-9), illustrates the actual profile form of this test The comparison shows that the actual profile form has a specified deviations at the crest and root areas Also the profile form (actual) consists of three areas, on each side The affect of the increment explain some of these deviations While the bounce of the stylus due to this velocity is another reason of this deviation However, table (6-2), gives a summary of for previous tests

The maximum difference between the actual and theoretical pitch is 0 0134 mm And the minimum difference is 0 0035 mm Thus the difference between the maximum and minimum one is 0 0099 mm Also the maximum difference between the actual and theoretical one is 0 01 mm and the minimum difference between the maximum and minimum is 0 007 mm. The difference between the increment is 0 0001 mm due to the very slow velocity and 0 0004 due slow one, 0 00062 mm due to the medium And it was 0 0018 mm due to the high velocity

The minimum inspection time was achieved due to the maximum velocity while the maximum time was due to the very slow velocity As shown in case number (1), and number (4)

6-2-3 The results of the bolt size M16

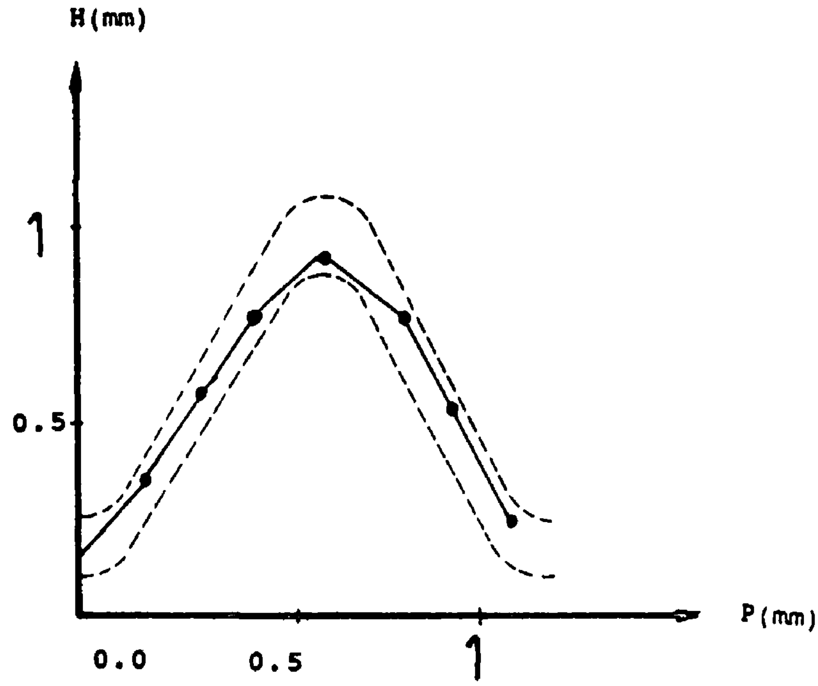


Figure (6-9)

Table (6-2)

V	17H/24	H	P	.5 ϕ	I	T
.5	.769	1.085	1.253	29.9	.0501	2
.83	.771	1.088	1.256	29.9	.0833	1.5
1.25	.763	1.077	1.243	29.9	.124	1
1.66	.776	1.094	1.264	29.9	.158	.753
2	X	X	X	X	X	X

	d(17H/24)	d(H)	d(P)	d(ϕ)	d(I)
1	.0022	.003	.0035	39.6"	.0001
2	.0042	.0059	.0068	39.6"	.0004
3	.0038	.0054	.0062	39.6"	.00062
4	.0092	.0117	.0143	39.6"	.007
5	X	X	X	X	X

Theoretical

17H/24	H	P	.5 ϕ	I
				.05
				.0833
.766	1.082	1.25	30	.125
				.156
				X

This bolt was manufactured by turning Its theoretical profile form is given in figure (6-10) The first test for this bolt size was carried out at the very slow velocity 0 5 mm/sec. Then the results were compared with the standard one, and they were within the specified tolerance zones

Also, the actual profile form which was developed according to these results, has superimposed on the theoretical form for comparison. The comparison as shown in figure (6-11), shows good agreement between the theoretical and actual profile form In the second test, the slow velocity 0 83 mm/sec, was used Also the results were compared with the reference one and they were within the specified tolerance zones

The actual profile form of this test is shown in figure (6-12) This figure shows the actual profile form superimposes on the theoretical one The comparison illustrates that there is a good agreement between these profile forms The main reasons were mentioned previously The third test was carried out at medium velocity 1 25 mm/sec. The results were compared with the same standard and they were within the specified tolerance zones

In figure (6-13), the comparison shows that the actual profile form, also has a good agreement with the theoretical one After that the test was performed at the high velocity 1 66 mm/sec in order to reduce further the inspection time of the operational cycle The results of this test were compared with the BS 3643 and they were

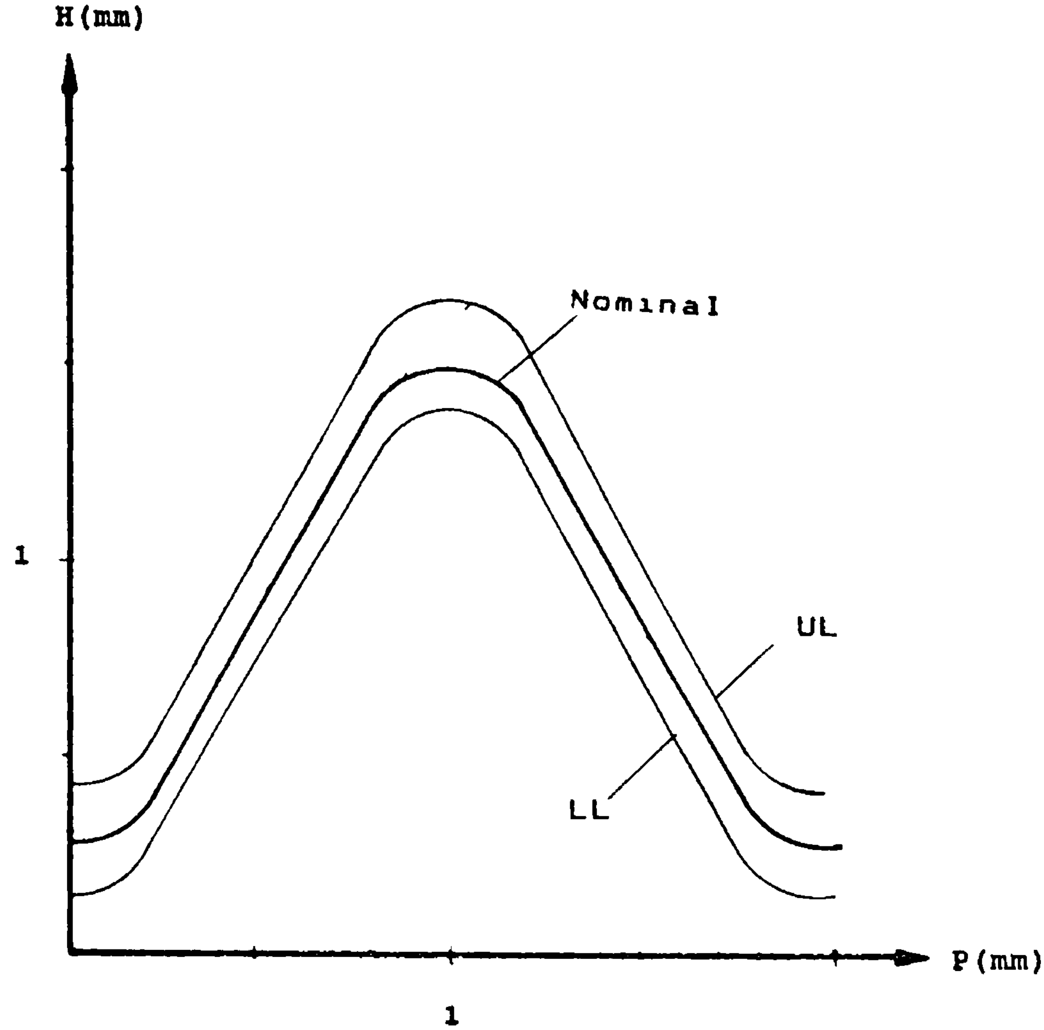


Figure (6-10)
The theoretical form of M16

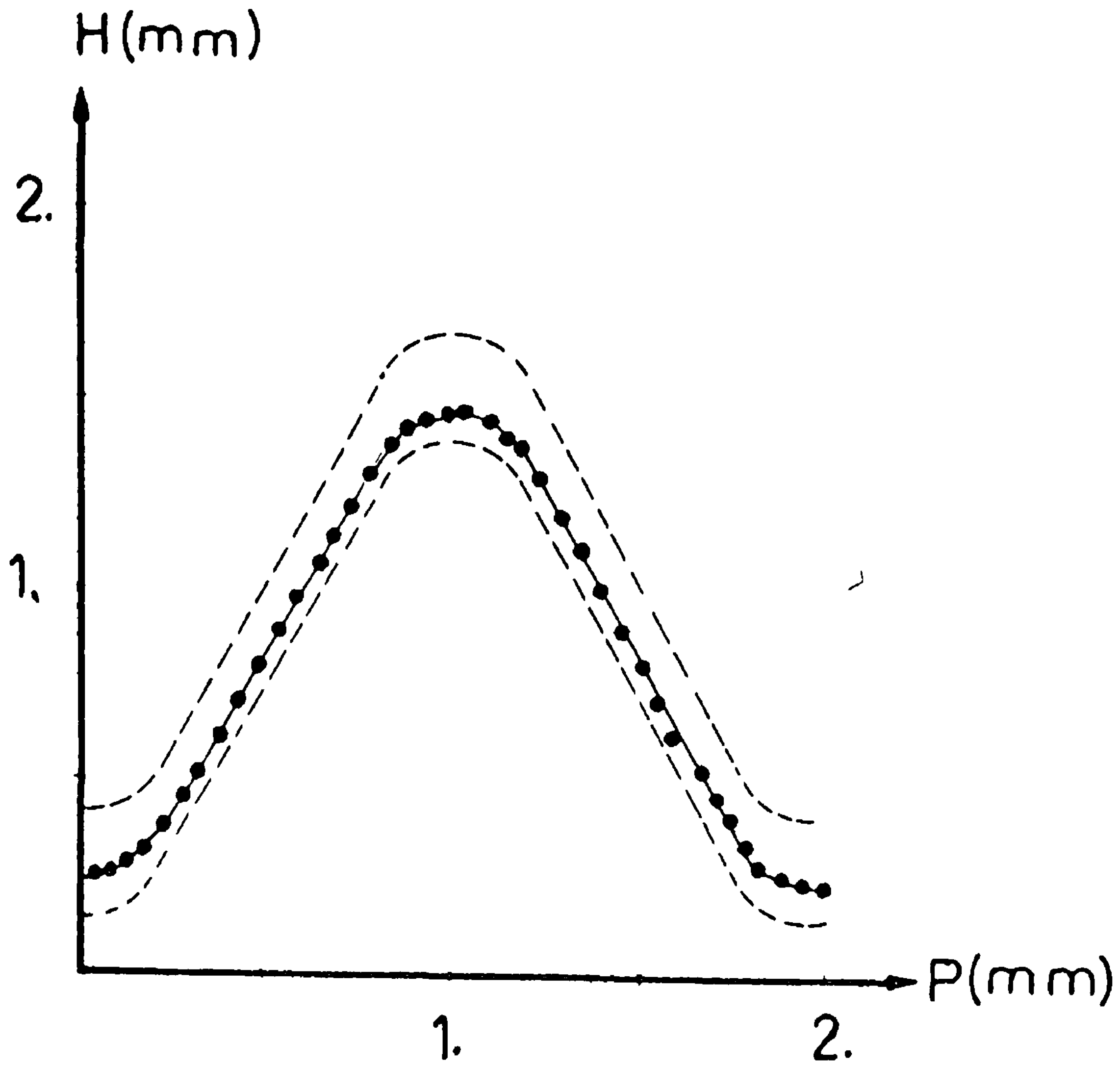


Figure (6-11)

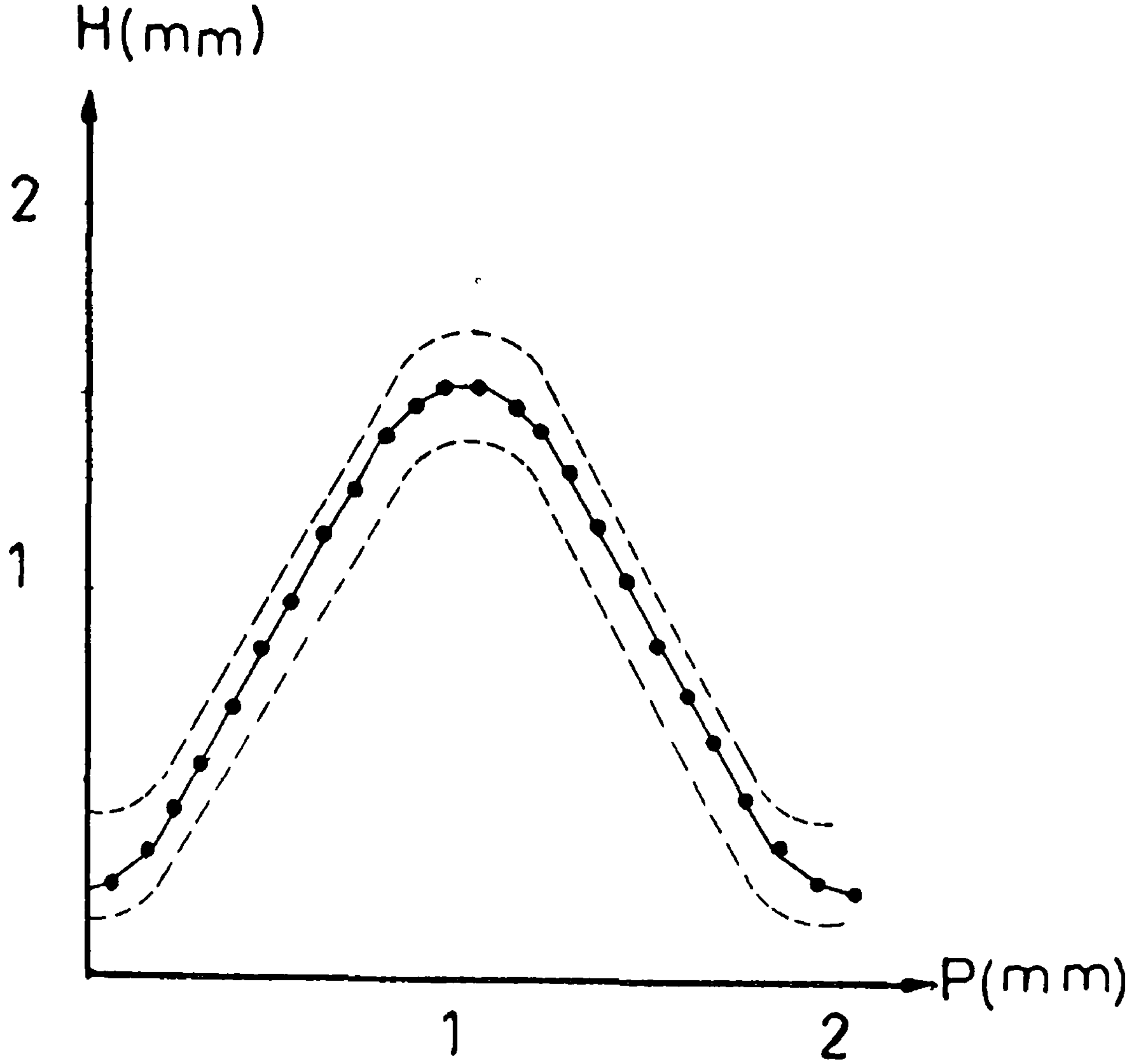


Figure (6-12)

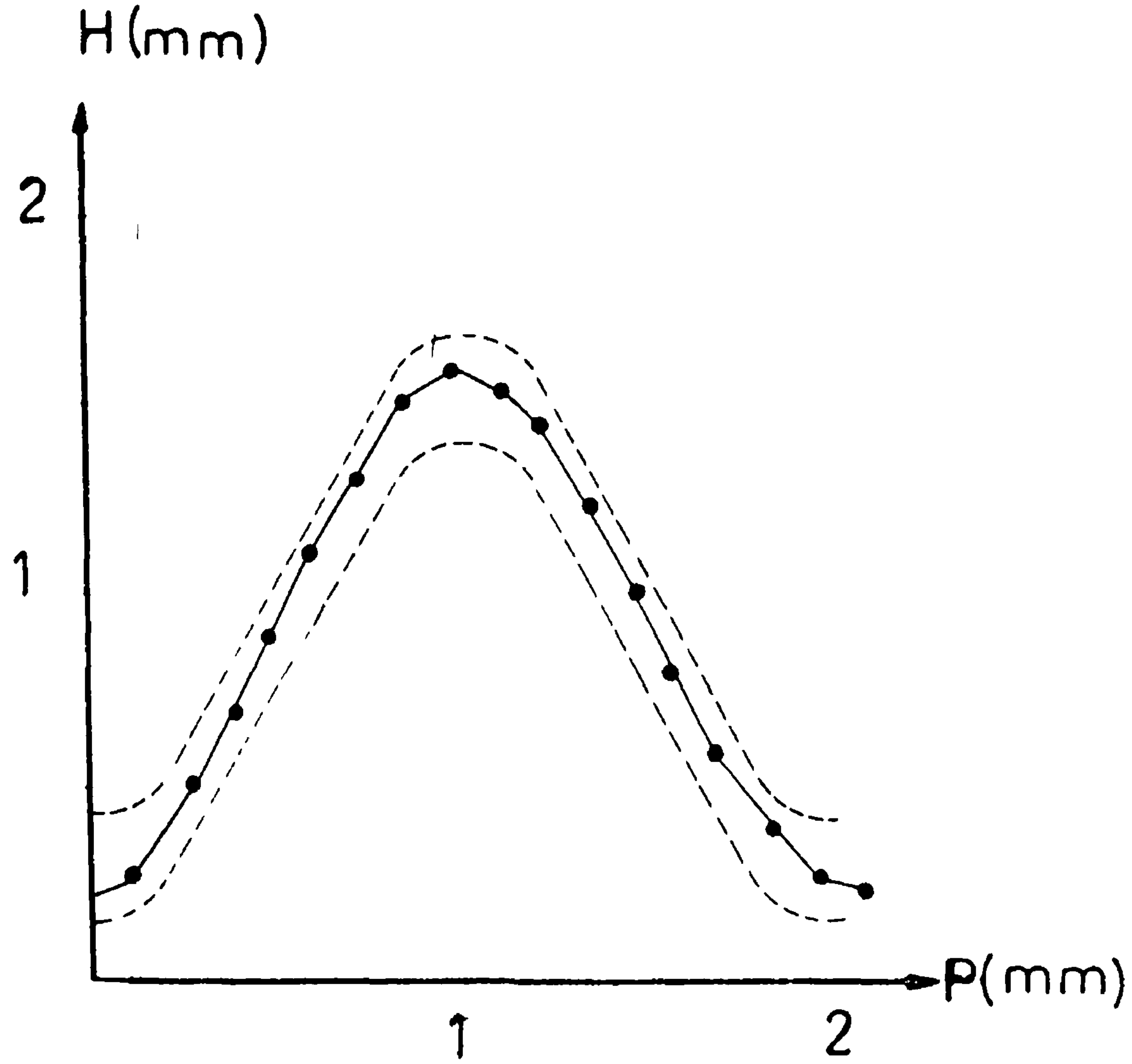


Figure (6-13)

within the specified tolerance zones Also, the actual profile form was superimposed on the theoretical one for the comparison, as shown in figure (6-14)

The comparison shows that the actual profile form still has a good agreement with the theoretical one in spite of the noticeable deformation at the crest and the root of the tooth In fact the first deformation was started from the third test. But it was not out of range and can not be discussed or analyzed However, one of the most important reasons is the bounce, which forced the stylus to miss some points especially at crest and root areas of the tooth profile In order to reduce the inspection time further more

The very high velocity 2 mm/sec was provided to perform the fifth form inspection Similarly, the results were compared with the reference one, and they were within the specified tolerance zones And also these results are the same of the previous one due to the slow velocity Thus, the same discussion can be seen adopted for this test. But the profile form was not the same More deformation can be seen at two different areas Also these, because of the bounce acts and the response time of (LVDT) These were explained previously Figure (6-15)

Table (6-3), gives a summary of the different results due to the various velocities The maximum difference between the actual and theoretical pitch was 0 068 mm, and the minimum one 0 0279 mm So, the actual difference between the maximum and the minimum was 0 0401 mm

While the difference between the actual and theoretical

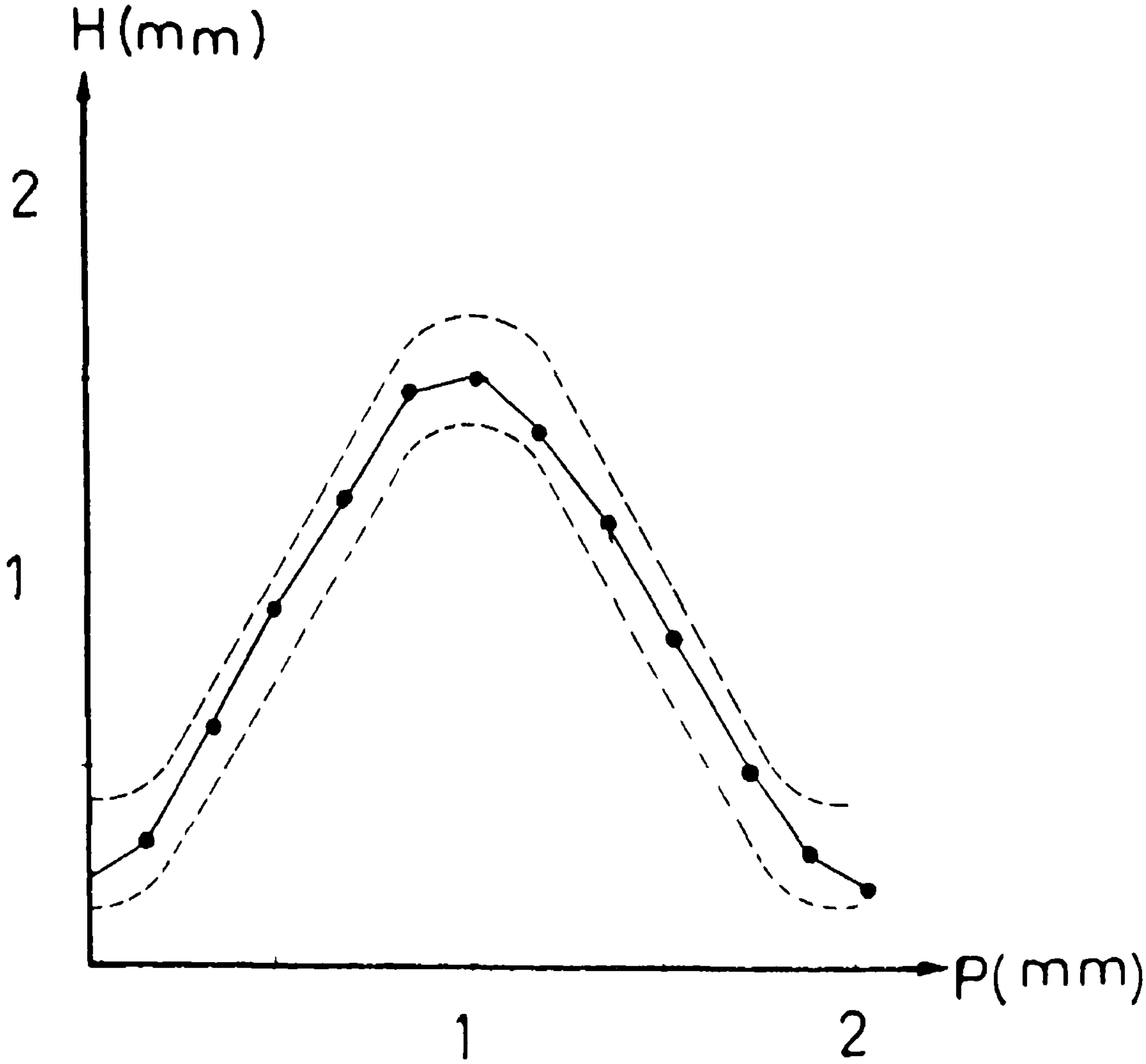


Figure (6-14)

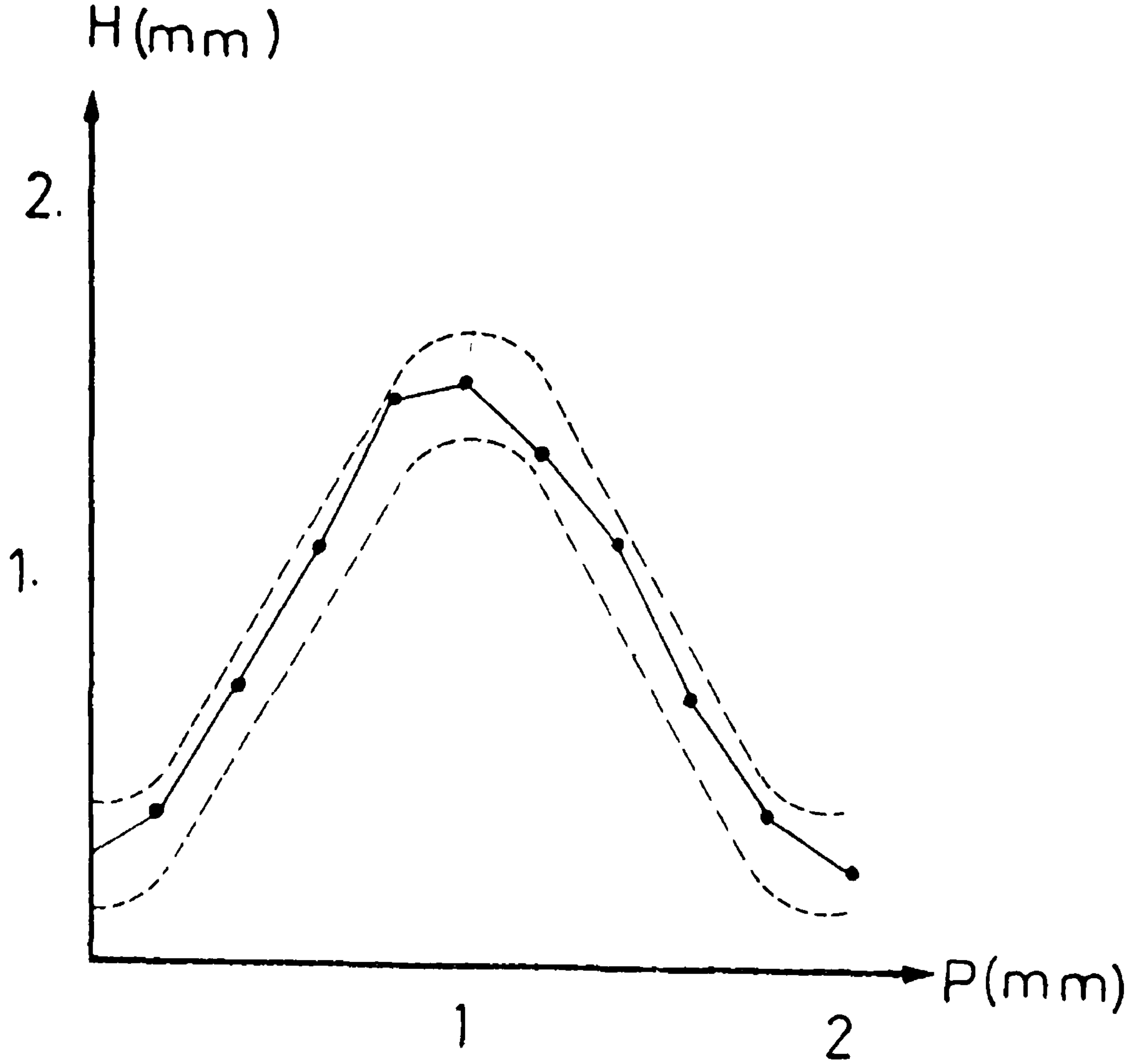


Figure (6-15)

Table (6-3)

Actual

V	17H/24	H	P	$.5\,\Phi$	I
.5	1.207	1.703	1.976	29.9	.0491
.83	1.244	1.756	2.027	29.9	.0811
1.25	1.269	1.790	2.068	29.9	.129
1.66	1.257	1.774	2.049	29.9	.170
2	1.244	1.756	2.027	29.9	.202 1

	d(17H/24)	d(H)	d(P)	$d(\phi)$
1	.0199	.0291	.033	39.6"
2	.0171	.0239	.0279	39.6"
3	.0421	.0579	.068	39.6"
4	.0301	.0419	.049	39.6"
5	.0171	.0239	.0279	39.6"

Theoretical

T	17H/24	H	P	.5 Φ	I
4					.05
2.4	1.226	1.732	2	30	.08
1.6					.125
1.2					.166
					.2

d(I)
.0009
.0011
.004
.004
.0027

depths the maximum one was 0 042 mm and as a minimum one was 0.0171 mm, thus the actual difference between these is 0.0249 mm.

Table (6-4), gives a summary of the form test for the three inspected bolts due to the different velocities. The table shows the different theoretical parameters and the actual one, also, it gives the results for each bolt size due a specified velocity.

Thus, from table (6-4), table (6-5), was derived This table gives the maximum velocity which can be provided for each bolt size, also table (6-6), gives the actual differences between the theoretical increment and the actual one, due to the three previous velocities mentioned in table (6-5)

6-3 The discussion of the helix path results

This discussion includes all results mentioned in chapter five

These results are compared with the standard one Then they are compared with each other Also, each figure consists of .

- ***Centre line*** **(CL)**
- ***Upper limits*** **(UL)**
- ***Lower limits*** **(LL)**
- ***Deviation axis*** **(Y)**
- ***Number of turns*** **(X)**

6-3-1 The results of bolt size M6

Table (6-4)

Bolt Size	V	17H/24	H	P	.5 Φ	I
	.5	.606	.856	.989	29.9	.0494
	.83	.604	.853	.985	29.9	.082
M6	1.25	.601	.848	.980	29.9	.122
	1.66	X	X	X	X	X
	2	X	X	X	X	X
	.5	.769	1.085	1.253	29.9	.0501
	.83	.771	1.088	1.256	29.9	.0837
M8	1.25	.763	1.0771	1.243	29.9	.124
	1.66	.776	1.0942	1.264	29.9	.158
	2	X	X	X	X	X
	.5	1.207	1.703	1.967	29.9	.0491
	.83	1.244	1.703	2.279	29.9	.0811
	1.25	1.2269	1.790	2.068	29.9	.129
	1.66	1.257	1.774	2.049	29.9	.170
	2	1.244	1.756	2.279	29.9	.2027

Table (6-5)

Bolt Size	V (mm/sec)				
	.5	.83	1.25	1.66	2
M6			X		
M8				X	
M16					X

(6-6)

B.S	T	A	D
M6	.125	.122	.003
M8	.158	.156	.007
M16	.2	.2027	.0027

Figure (6-16), shows the result due to the angular velocity 3 13 rad/sec , for five revolutions

The travelling distance used was 94 24 mm, hence giving a total inspection time of 10.02 sec. The figure illustrates that the helix path points varies between the positive and negative directions It can be noticed that the maximum deviation is 0.051 mm in the positive direction and 0 058 mm in the negative direction. Also, the minimum deviation in the positive direction is 0 002 mm and 0 004 mm in the negative direction Therefore, the actual difference is 0 0109 mm

As a result of comparing the actual deviation with admissible one this difference will be 0 075 mm The same velocity was used to test this bolt size, but only for one revolution

The result as shown in figure (6-17), is very close to the previous one The maximum deviation increases by 0 01 mm in the positive direction Where it decreases by 0 006 mm in the negative direction The comparison of the actual difference between the previous test and this one, shows a difference equal to +0 003 mm And the comparison with the standard gives a difference equal to 0 072 mm This means that the accuracy due to this velocity varies within $\pm$ 0 003 mm

6-3-2 The results of the bolt size M8

The angular velocity 3 125 rad/sec, was used firstly, in order to perform the helix path inspection of

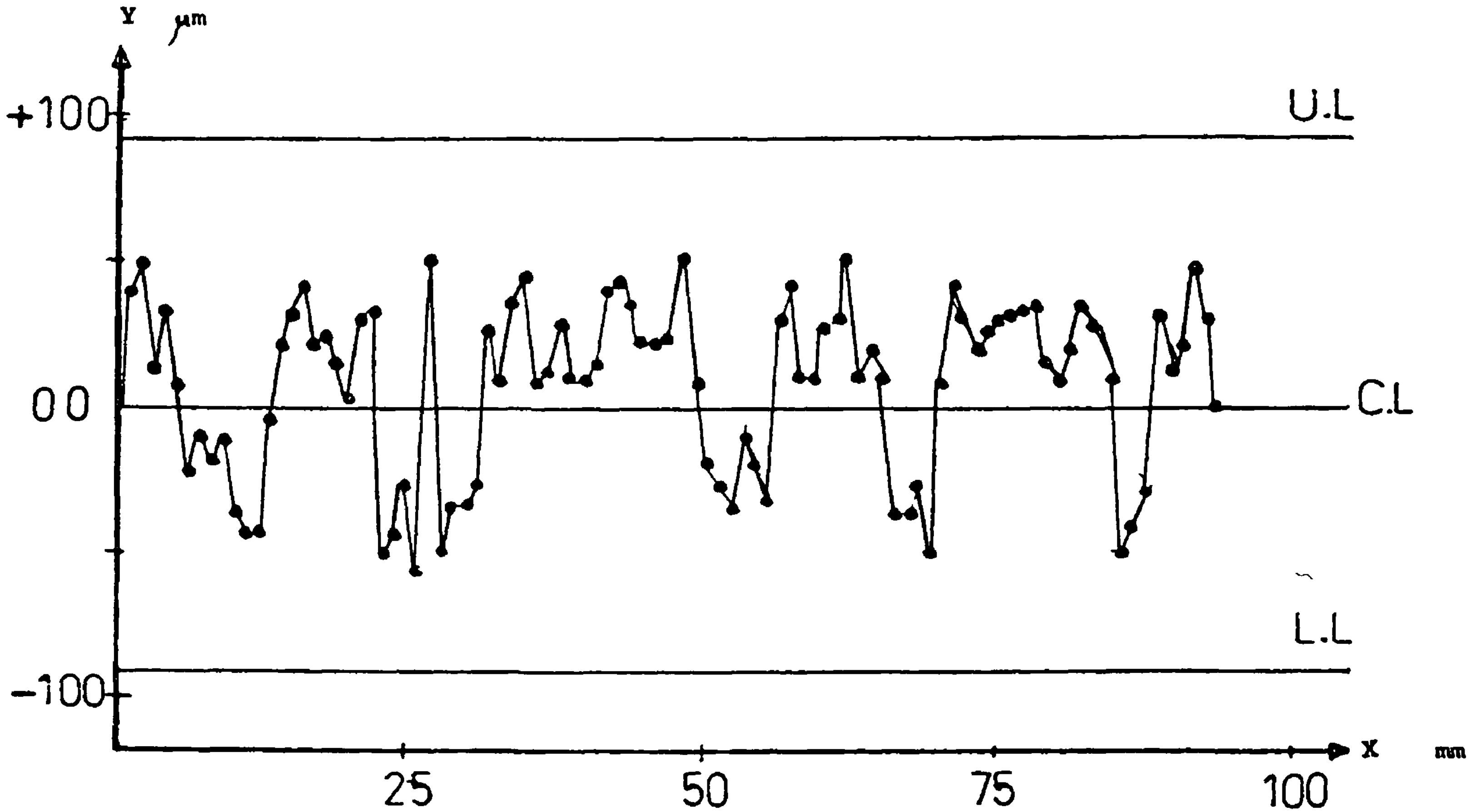


Figure (6-16)
HELIX inspection of
M6, five revolution, w=3.125 rad/sec

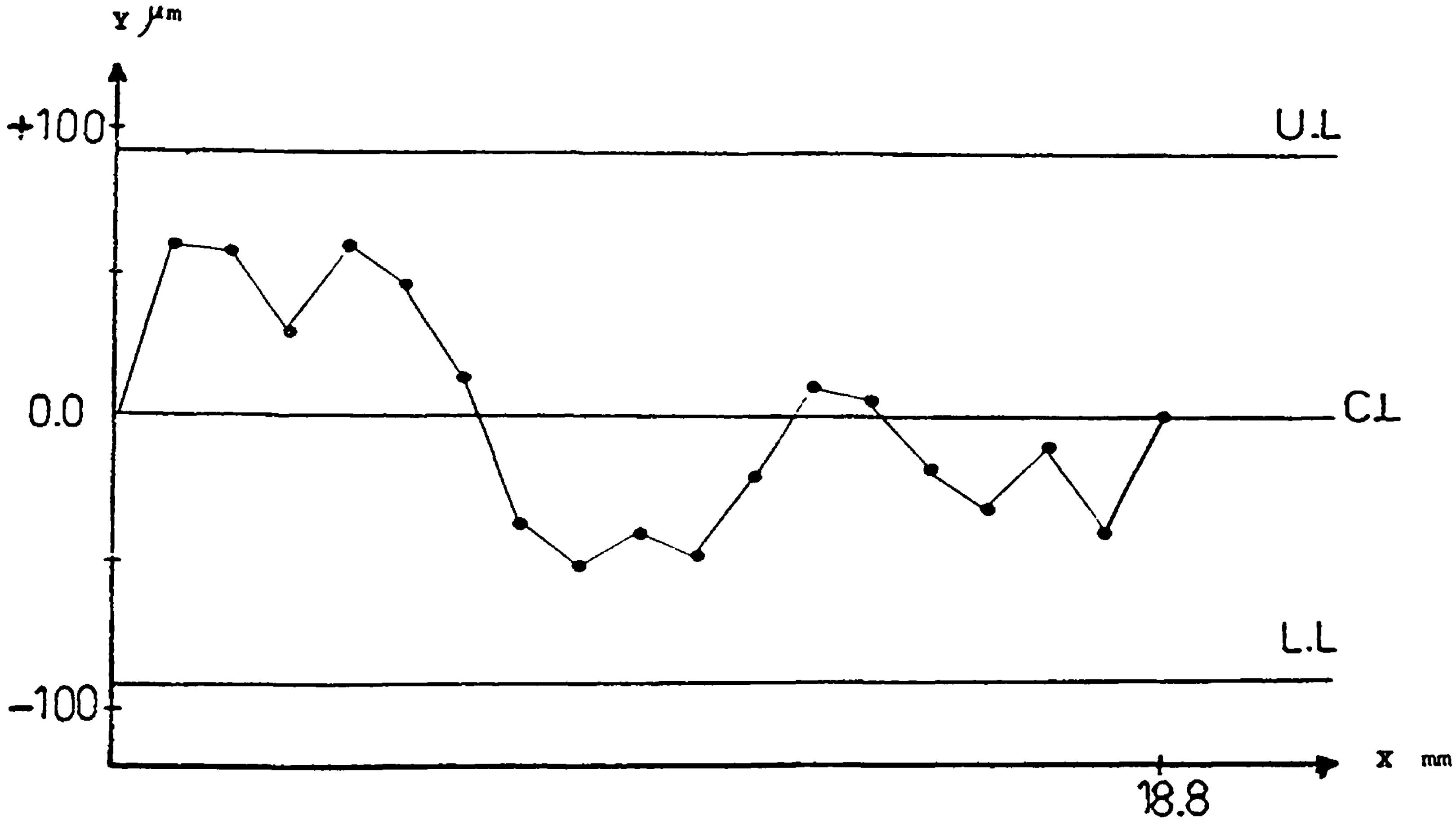


Figure (6-17)
HELIX inspection of
M6, one revolution, w=3.125 rad/sec

this bolt size.

Figure (6-18), shows the result due to this velocity. Five revolution were accomplished, the travelling distance is 125 66 mm, while the total time is 10 sec The maximum deviation due to positive direction is 0 062 mm And it is 0 050 mm in the negative direction

It can be seen that after one revolution these maximum deviations are reduced to become 0 040 mm due to the positive direction and 0 045 mm due to the negative direction The actual deviation of this test is 0.112 mm But the comparison with the standard one shows that these deviation is 0 096 mm, which is 0 048 mm for each direction

the result of one revolution due to the same velocity is given in figure (6-19) The maximum deviation in the positive direction is less by 0 008 mm and more by 0 005 mm in the negative direction

Thus the difference between the maximum values of this test is 0 097 mm, so the comparison with the standard one shows that the actual result is 0.055 mm far from each limit Hence, the accuracy of this result is within +_0 0075 mm

In order to reduce the inspection time, a higher angular velocity 6 25 rad/sec, was used The total time for inspecting five turns is 5 0264 sec, that means one second for each turn The effect of this high velocity can be seen in figure (6-20)

The maximum deviation due to the positive direction 0 065 mm, and 0 080 mm, due to the negative direction,

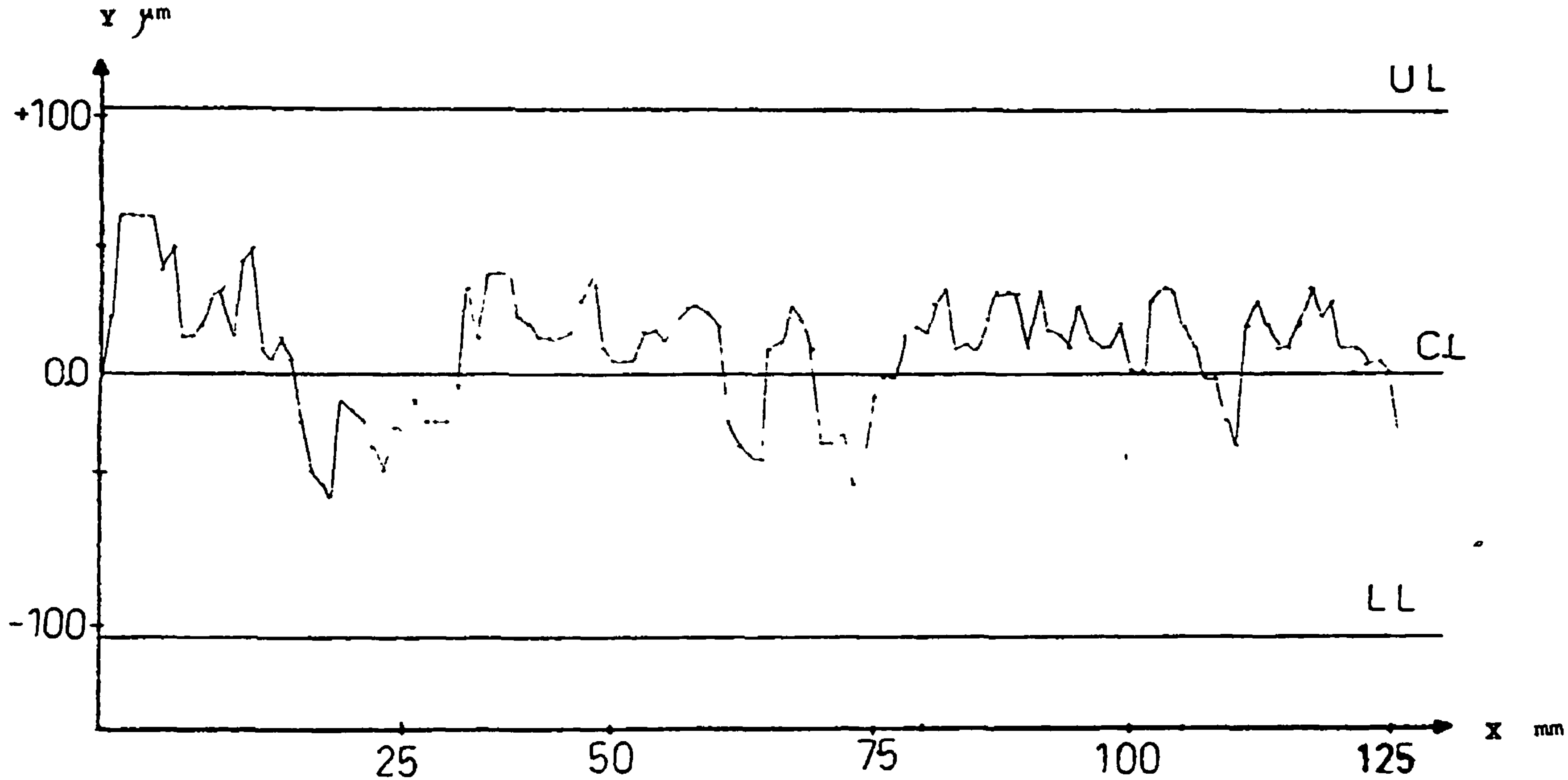


Figure (6-18):
HELIX inspection of
M8, five reolution, w=2.84 rad/sec

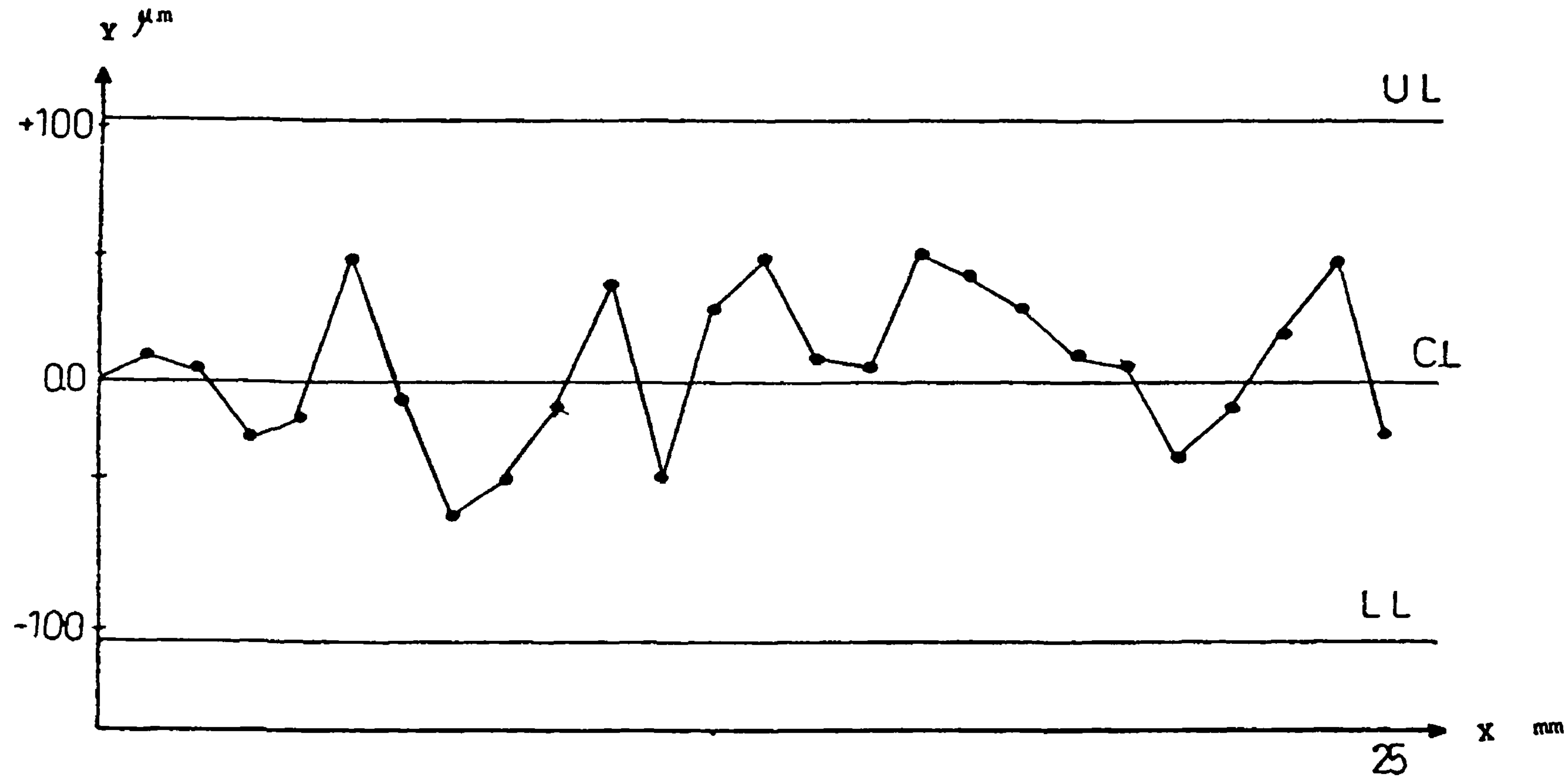


Figure (6-19)
HILEX inspection of
M8, one revolution, w=2.84 rad/sec

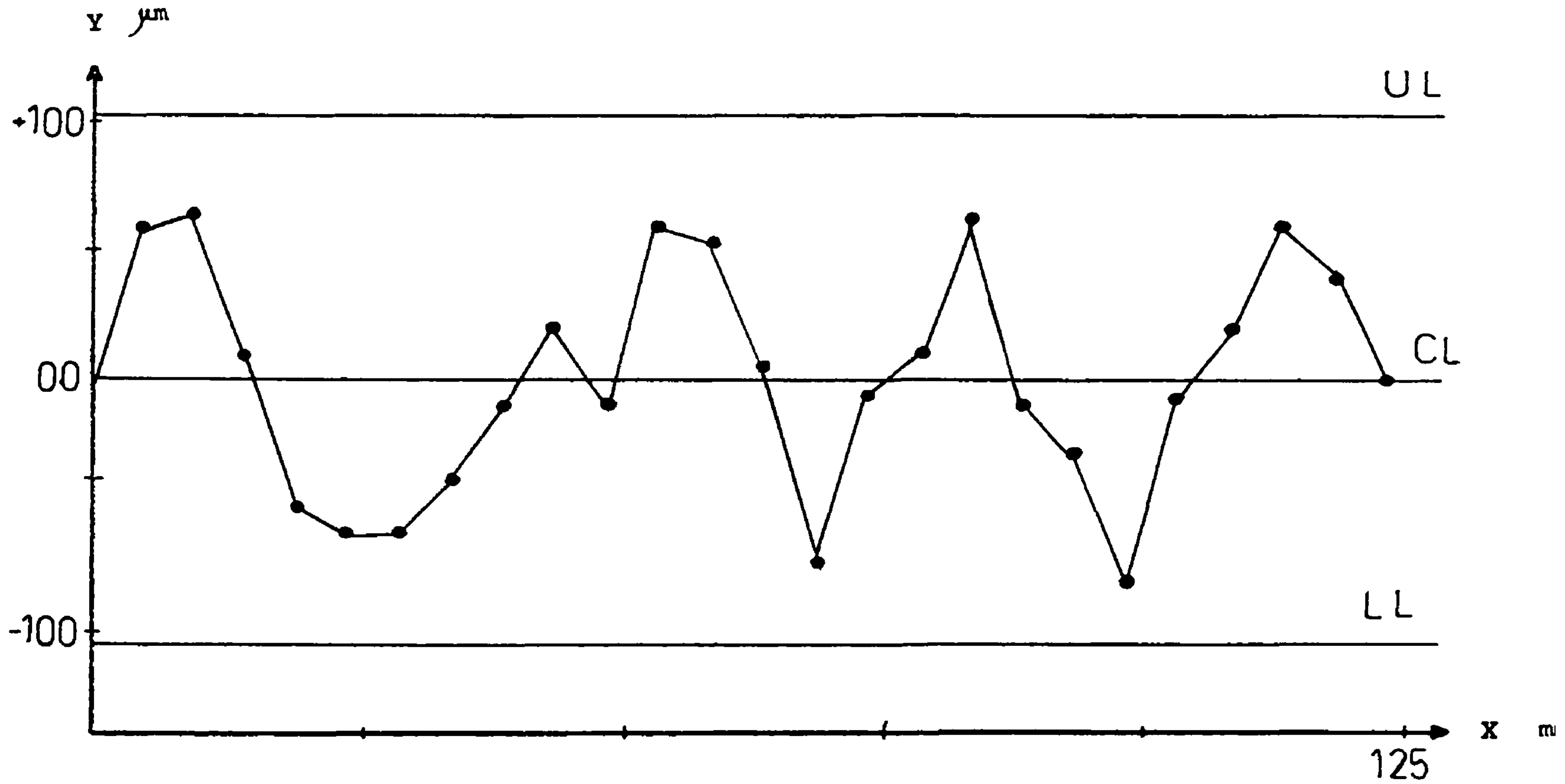


Figure (6-20)
HELIX inspection of
M8, five revolution, w=6.25 rad/sec

the difference is 0.145 mm, the comparison with the standard one shows that this difference is 0 0315 mm The same velocity was used only for one revolution Also, the maximum deviation increases by 0.005 mm, while the other one stays as it was 0.080 mm However, it can be noticed that a few points were in a bad position, these are due to this high velocity, which is forced the stylus to bounce at some points. The bounce value can be found since a comparison is made between these cases and the two previous one This value is 0 048 mm. Also this test is illustrated in figure (6-21)

6-3-3 The result of the bolt size M16

Figure (6-22), shows the result due to the slowest angular velocity 1 42 rad/sec The travelling distance 251 32 mm represents the five revolutions which take 22 sec , to be traced by the stylus
The maximum deviation - 0 080 mm can be seen due to the negative direction. While the maximum one due to the positive direction can be seen is 0 092 mm
The actual difference between these deviations is 0172 mm. While these deviations are within the theoretical one by 0 06 mm for the positive direction, and 0 072 mm for the negative direction Then the difference between the theoretical and the actual one is 0 132 mm The same velocity was used only for one turn The results shown in figure (6-23), illustrates that the deviation increases by 0 033 mm due to the positive direction While it

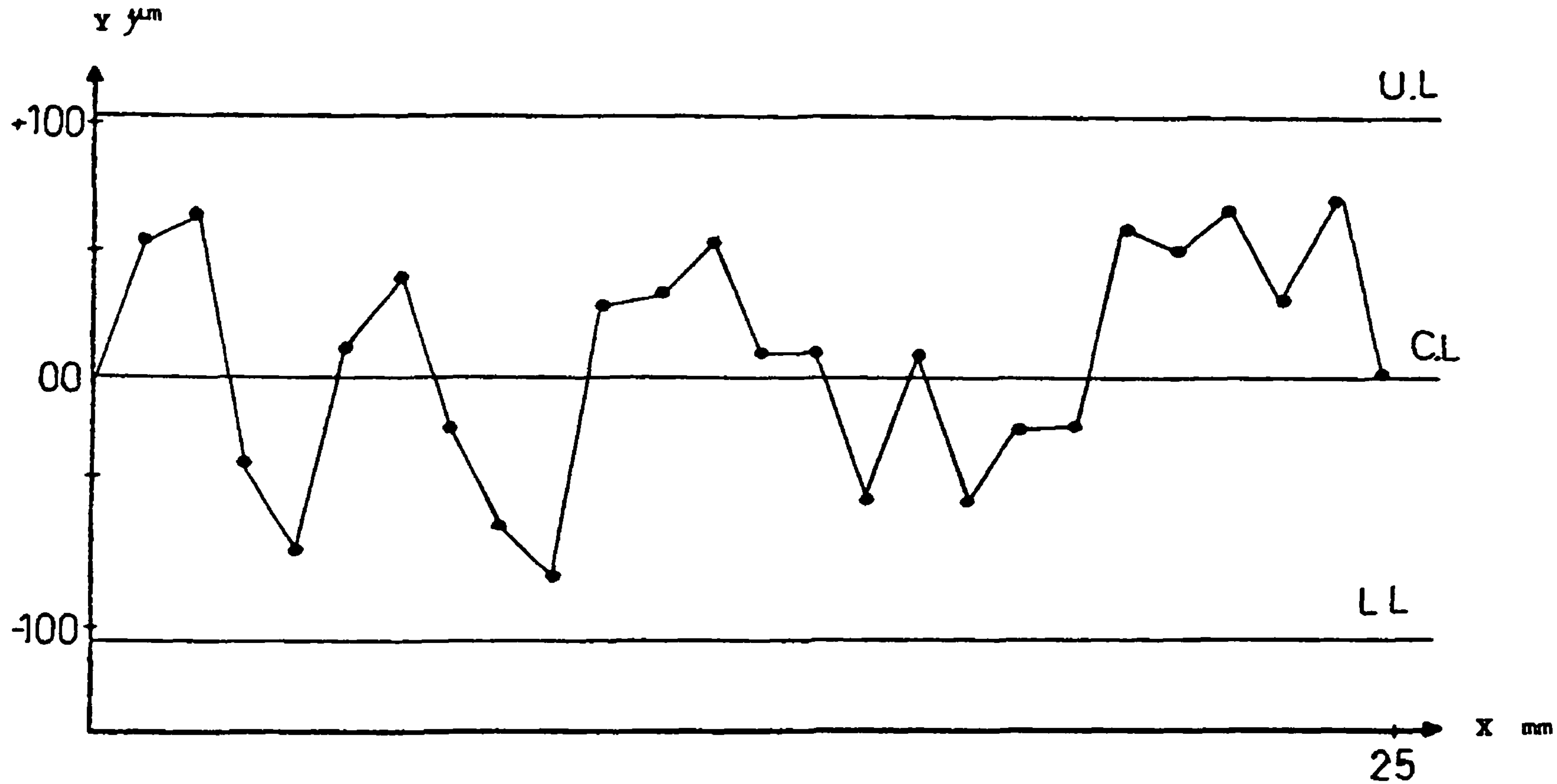


Figure (6-21)
HELIX inspection of
M8, one revolution, w=6.25 rad/sec

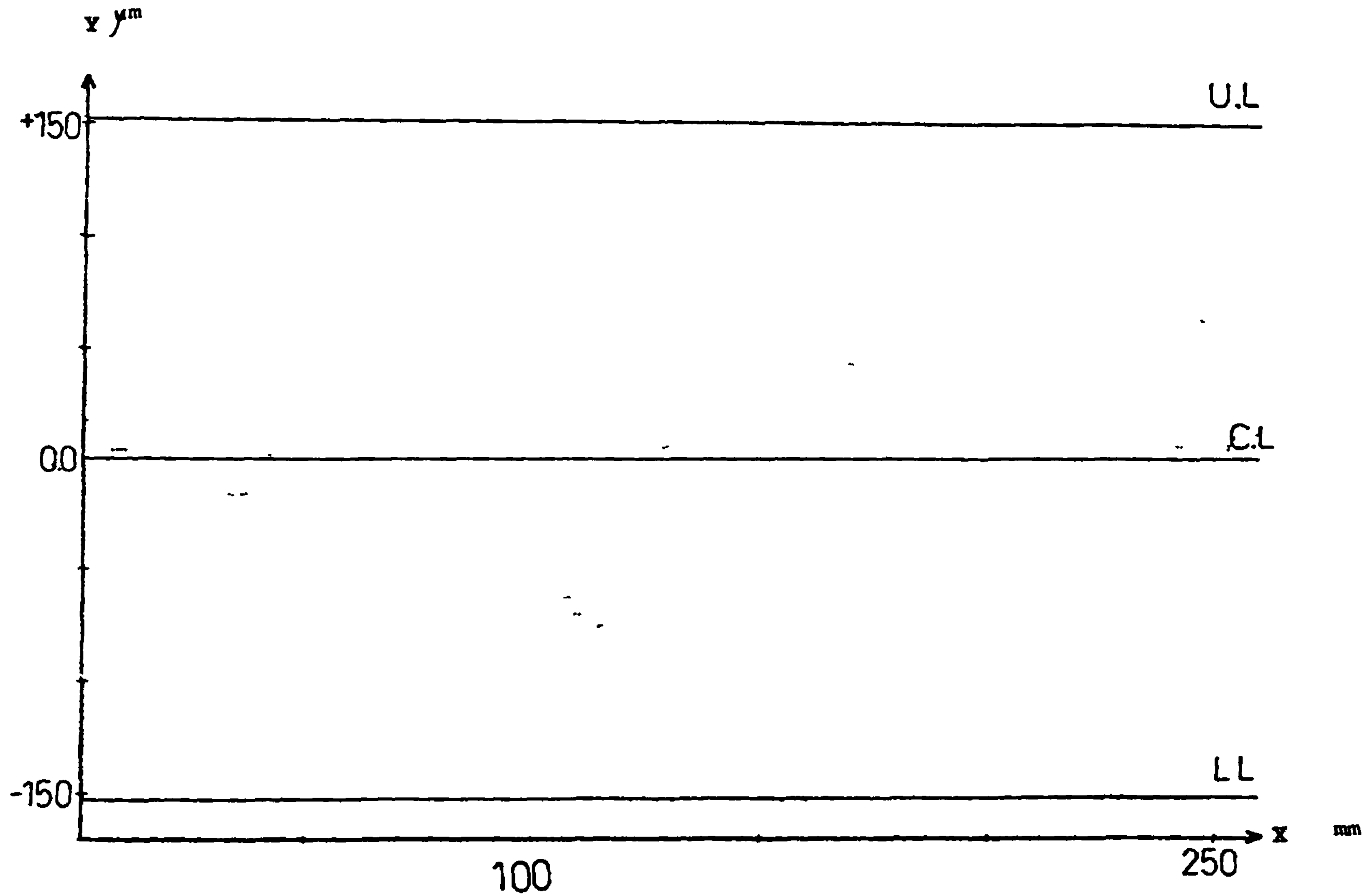


Figure (6-22)
HELIX inspectin of M16
five revolution, w=1.42 rad/sec

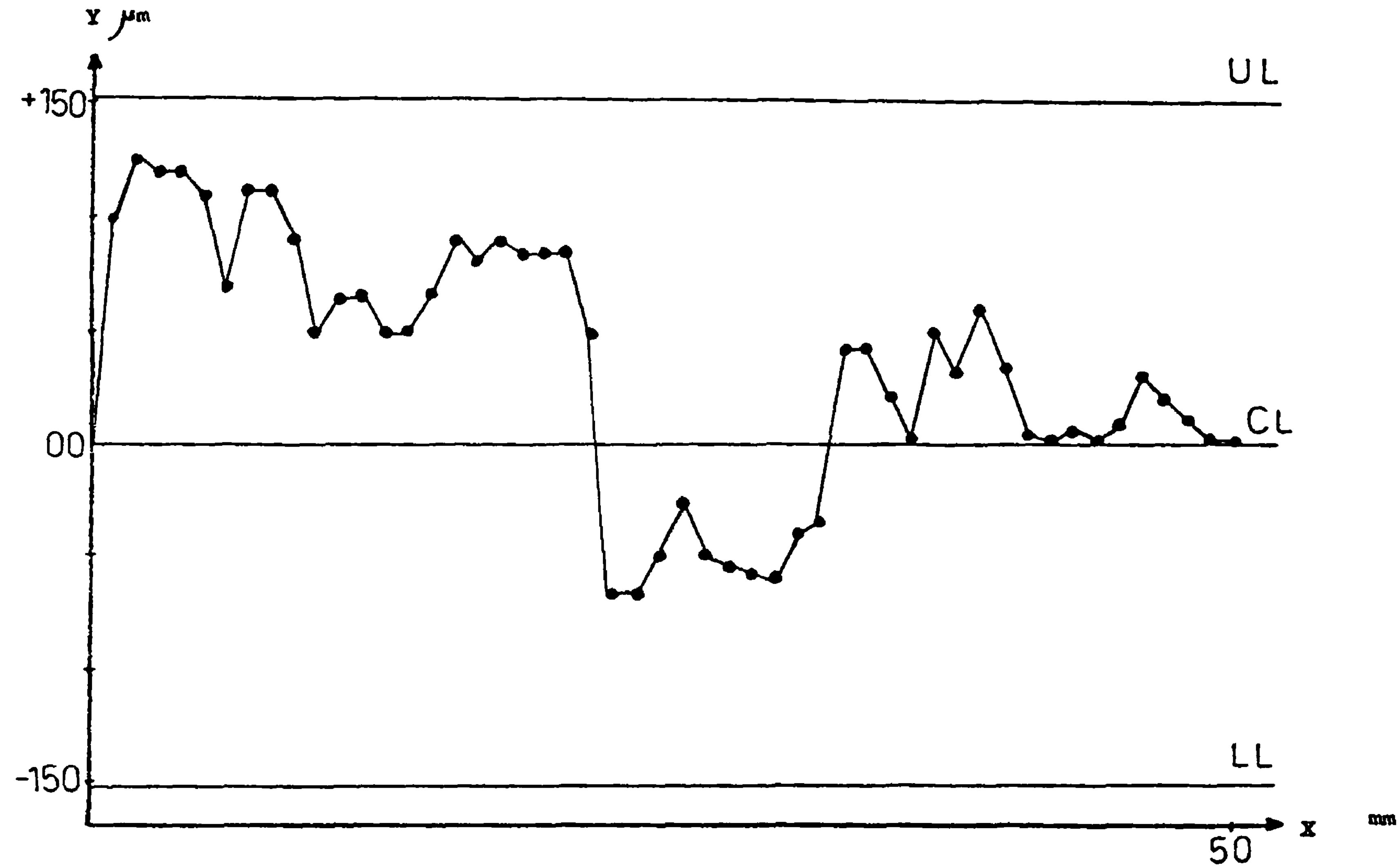


Figure (6-23)
HELIX inspection of M16
one revolution, w=1.42 rad/sec

decreases by 0 014 mm in the negative direction.

The comparison between the actual difference of this test and the previous one was increased by 0.019 mm But the difference between the deviation and the limits of the standard one has been affected by a very small value equal to 0 0035 mm. The second velocity was used 2.84 rad/sec Figure (6-24), shows the result of the five revolutions The stylus starts from the maximum points which gives a deviation equal to 0.125 mm due to the positive direction.

It can be seen that all the deviation through the first revolution were due to the positive direction However the maximum deviation due to the negative direction is 0 060 mm Thus the total deviation is 0 185 mm, and the actual difference is 0.119 mm The same velocity was used for one revolution only. The results can be seen in figure (6-25) The maximum deviation due to the positive direction is 0 100 mm, and 0 100 mm due to the negative direction The difference between these results and the previous one is 0.015 mm. While the actual difference compared with the theoretical one is 0 052 mm

The two previous results were within $\pm$ 0 01 mm accuracy The total time for five revolution was 12 sec. In order to reduce further more the inspection time, a very high angular velocity of 6 25 rad/sec was used. The total inspection time 5 023 sec for five revolution

The result as shown in figure (6-26), has a very small difference compared with the previous one

The maximum deviation due to the positive direction is

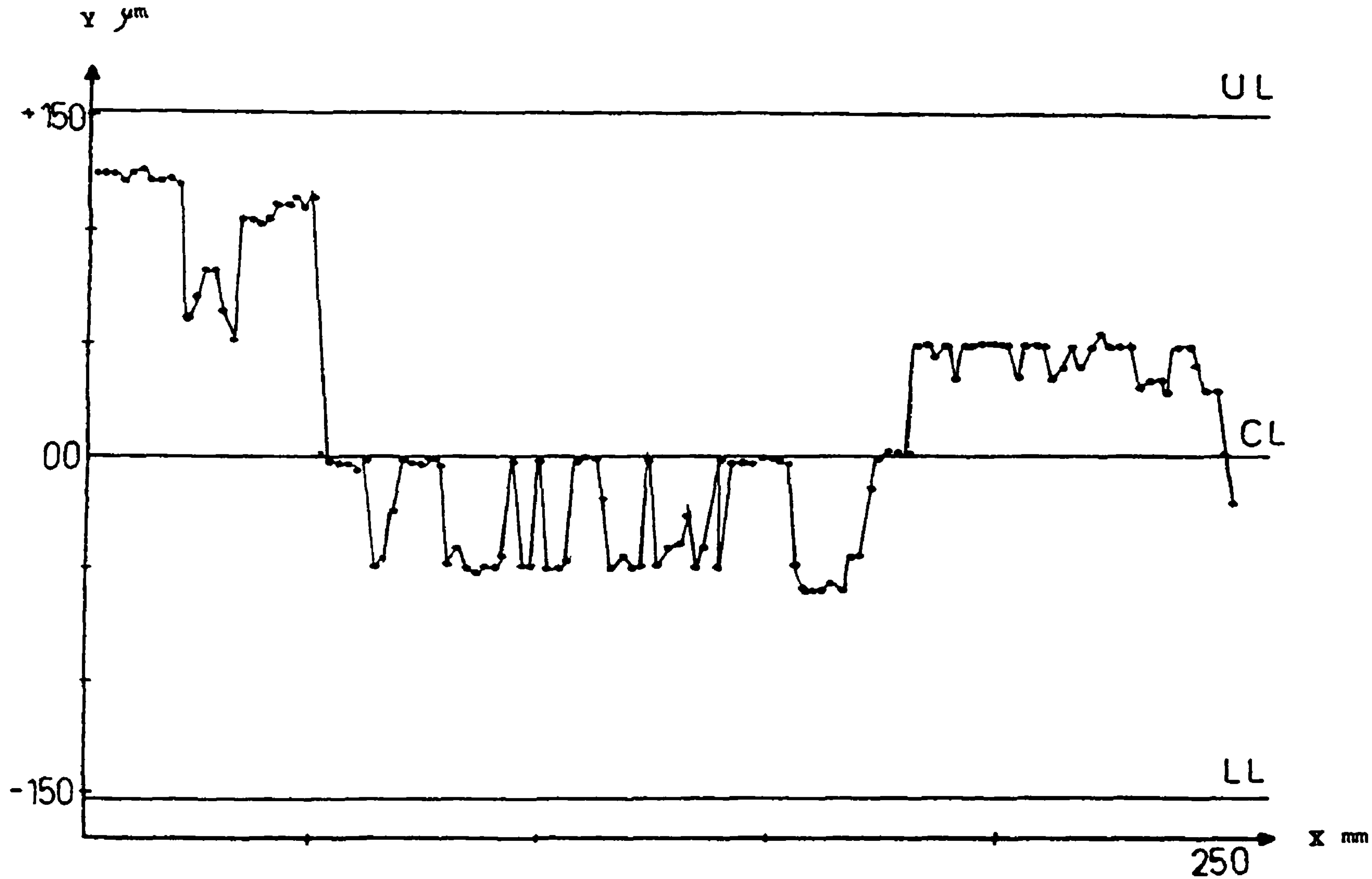


Figure (6-24).
HELIX inspection of M16
five revolution, w=2.84 rad/sec

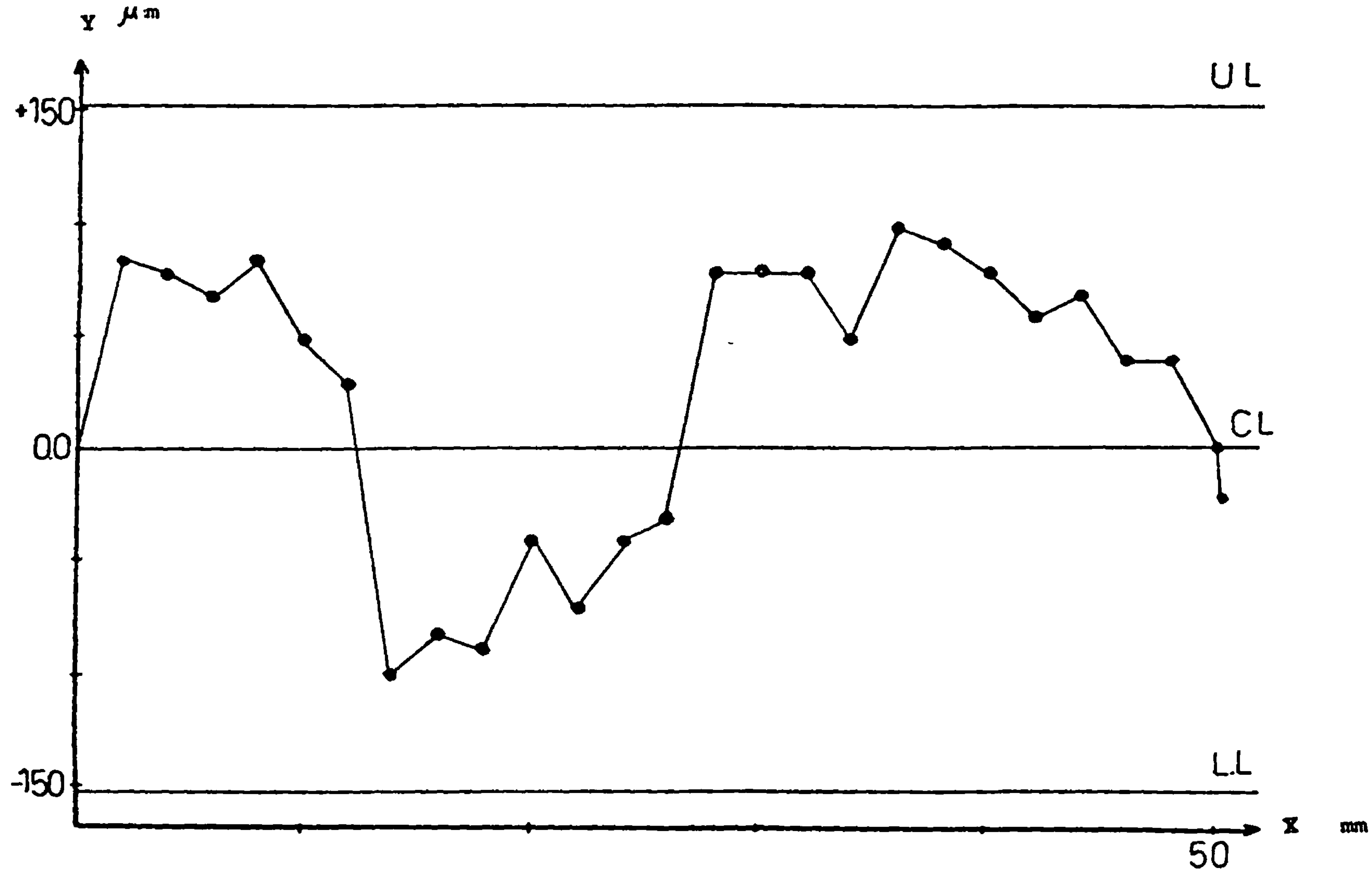


Figure (6-25)
HELIX inspection of M16
one revolution, w=2.84 rad/sec

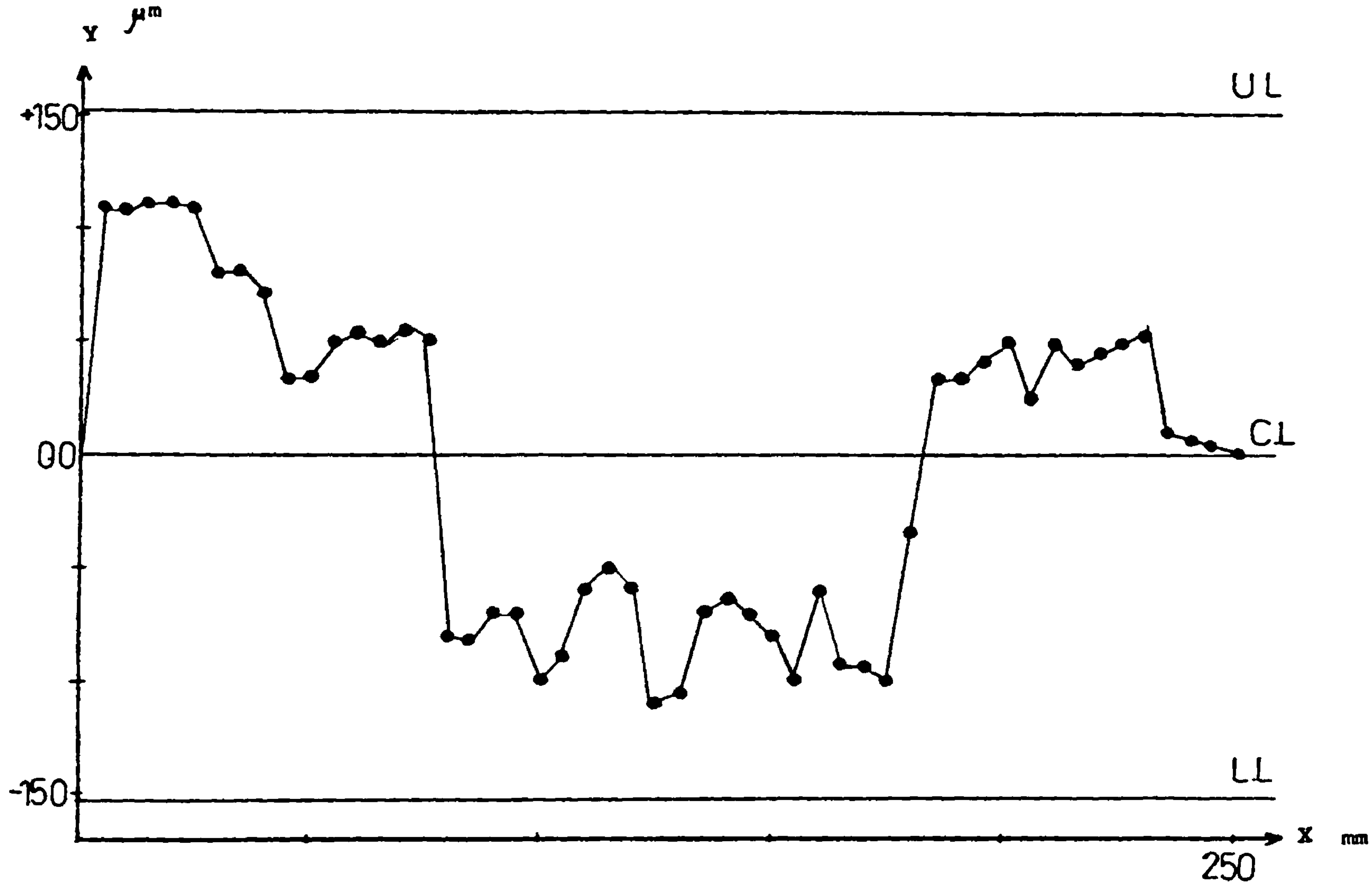


Figure (6-26)
HELIX inspection of M16
five revolution, w=6.25 rad/sec

0 112 mm and - 0.110 mm due to the negative direction So the difference between the previous one is equal to 0 022 mm It can be seen here, the effects of the high motion which causes the bounce of the stylus at a specified points Also, it can be noticed the strong relation ship among the deviations and the velocities.

The last velocity can be adopted for this size of bolt and a correction factor must be added in order to achieve a higher degree of accuracy.

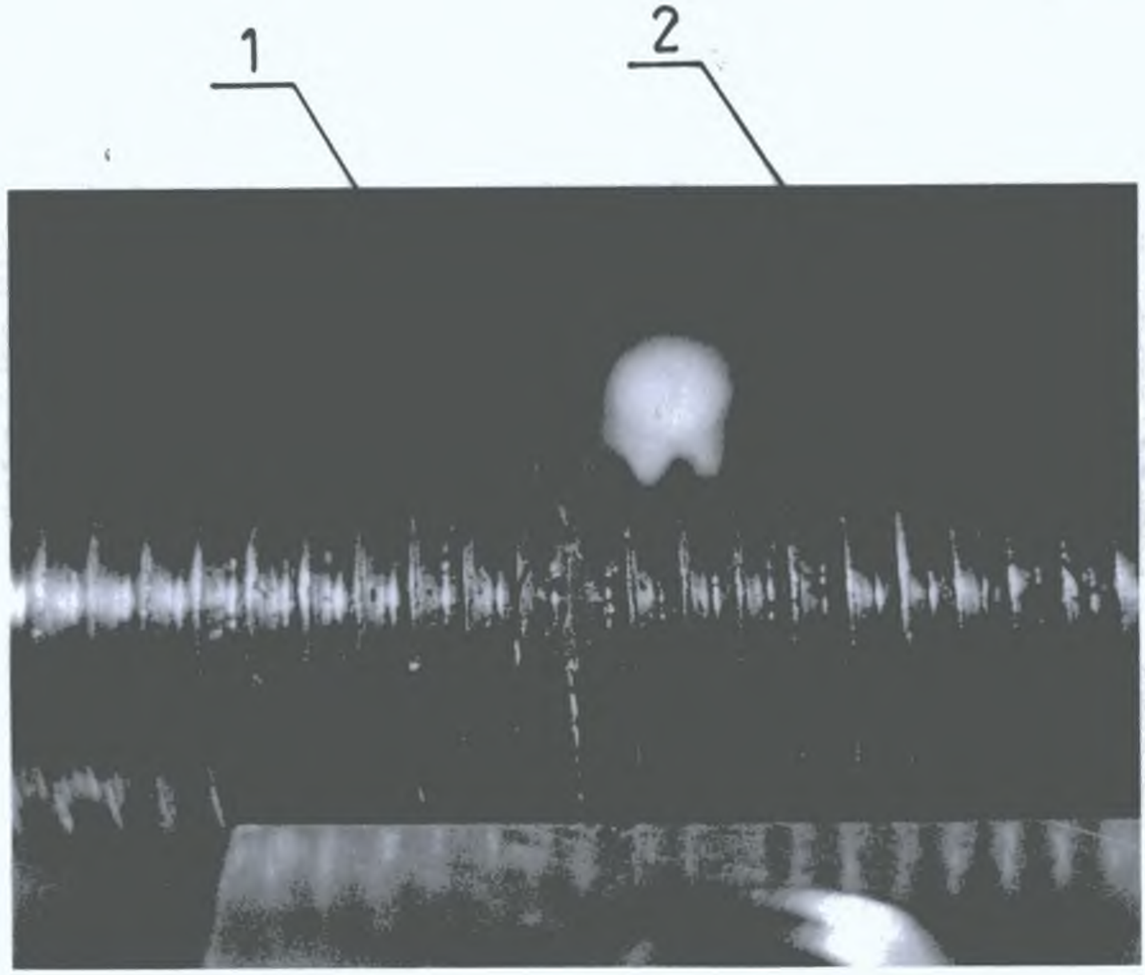
6-3-4 Artificial defects

Two types of defects were made artificially , in order to detect them, using one or more of the previous velocities

The first defect was made at the crest of the tooth of thread, in order to deform its profile form While the second defect was made at the root of the tooth of the thread, in order to deform its helix path

(1) - Form inspection

The artificial defects were made for the bolt size M16, which was manufactured by turning A small part of its crest was removed by milling The slow velocity 0 83 mm/sec was used in order to detect this defect The actual profile form as shown in figure (6-27), was developed and superimposed on the theoretical one for comparison The comparison shows the disconformity


1
2

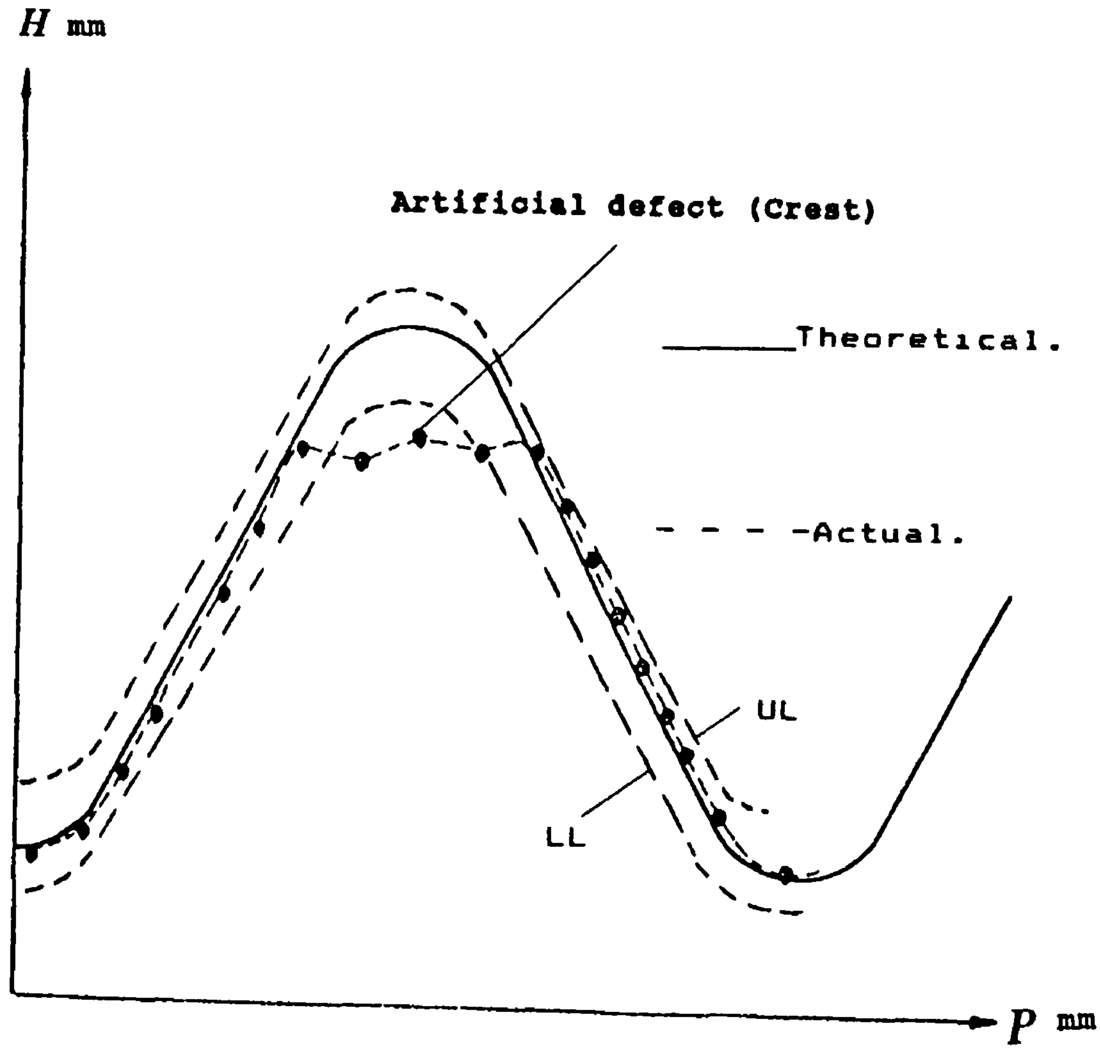
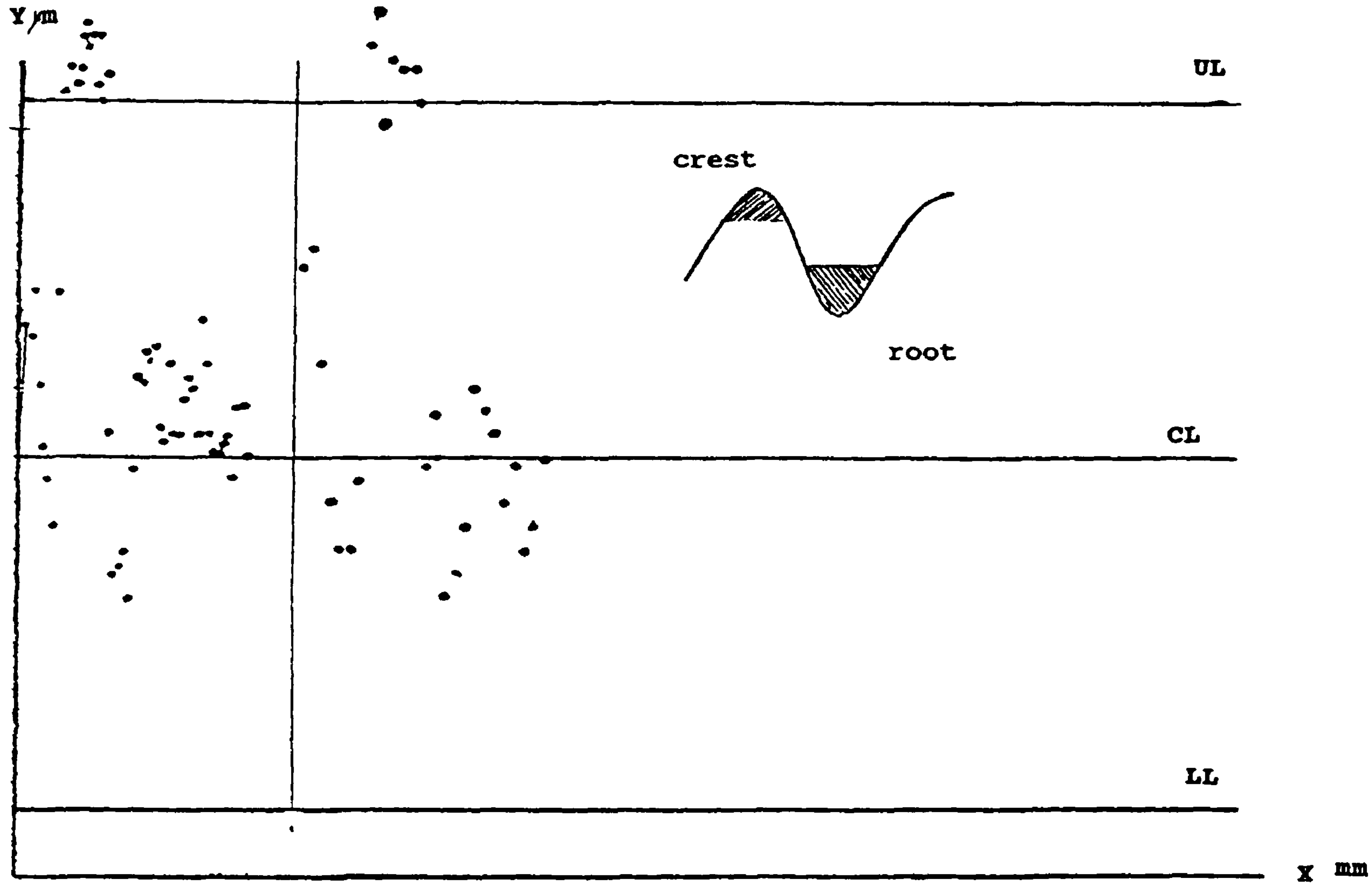


Figure (6-27)

between the actual and the theoretical crests.
Also, these results were compared with the standard one. The actual difference between the actual and theoretical depth is 0 3269 mm
This difference includes the equivalent size which was removed by milling. In addition, the figure shows two different points at the cutting surface. The first one is 0 86 mm and represents the minimum output at that surface while the second one which represents the maximum is 0 91 mm Thus the test, also, gives some information about the texture of the cutting surface

(2)- Helix path inspection

Another artificial defect was made on the helix path of the same bolt size
Figure (6-28), illustrates the two results, which were extracted due to two different angular velocities The first test was for the angular velocity 1 42 rad/sec
The maximum deviation is out of the upper limit by 0 040 mm The second test was for the angular velocity 2 84 rad/sec The maximum deviation can be seen to be out of the upper limit by 0 045 mm Hence, the actual difference between the result due to the first and second velocities is 0 006 mm This difference refers to the experimental error and the affect of the higher velocity



Figure(6-28)

CHAPTER SEVEN

7- CONCLUSION.

7-1 Conclusion

The automatic measuring system, described previously can be used for inspecting external screw threads of size M4 up to M36

The operational cycles time is based on the bolt size

The measuring principle is based on moving a stylus over the profile form of the thread or along its helix path

The operational cycle has a specified consequence for each type of test

The displacement, which is converted into an electrical signal interfaced and processed by a personal computer special *software* was developed, in order to

(a)- Process the signals

(b)- Control the motors

(c)- Sorting

(d)- Computing

(e)- Comparing

(f)- Displaying

(g)- Plotting

The experiments performed on three different bolt sizes, consequently they were M6, M8 and M16.

In order to achieve the minimum inspection time for the form and helix path inspection different ranges of the linear and angular velocities were used The maximum linear velocity of 2 mm/sec was used, in order to perform the profile form inspection for the bolt size M16 And the minimum linear velocity was used, also, to perform the profile form inspection 0 5 mm/sec, for the three bolt sizes

While the minimum angular velocity was used to perform the helix path 1 42 rad/ sec, for the bolt size M16.

The minimum range of velocity was located according to special considerations, with regard to the minimum power rate required to drive the motors While the maximum one was controlled considering the bounce affects

From the experimental results discussed, it can be concluded that

(1)- ***The maximum*** linear velocity which can be used in order to inspect the profile form of the bolt size M6, is 1 25 mm/sec, and the maximum angular velocity which can be used in order to inspect the helix path of the same bolt size is 3 13 rad/sec

(2)- ***The maximum*** linear velocity which can be used, in order to inspect the bolt size M8, is 1 66 mm/sec and the maximum angular velocity which can be used in order to inspect the helix path of the same bolt size, is 6 25 rad/sec

(3)- ***The maximum*** linear velocity which can be used, in order to perform the form inspection is 2mm/sec, and the maximum angular velocity in order to perform the helix path inspection of the same bolt size is 6.25 rad/sec.

(4)- ***The experiment*** shows that short and very high velocity mean less accuracy vice versa.

(5)- ***One of*** the effects of the bounce decreases the point of accuracy

(6)- ***The stylus*** move smoothly due to the very slow velocity

(7)- ***A high*** degree of accuracy of 0 009 mm was achieved

(8)- ***The resolution*** of the system is 0 000002 mm

(9)- ***The movement*** of the stylus follows the increase/decrease due to the rate of change of the stylus speed at the root and crest area of the tooth And this explains, why the stylus bounce at the root or crests due to the very high velocity

(10)- ***The minimum*** increment which was achieved is 0 0491 mm and the minimum difference was 0 0001 mm While the maximum increment is 0.2027 mm and the maximum difference is 0 004 mm

This system, with some modification can be used for inspecting other types of objects Also it can be used for testing the surface texture

7-2 Recommendation for further work

In order to improve the operational cycles of this automatic inspection system, an automatic feeding process can be added to one side

While, another automatic removing process can be added to the other side, thus, the feeding, inspecting, removing are accomplished consequently.

Also, this system with a suitable modifying, can be built with the machine which produces the external screw threads, and screw components.

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APPENDIX (A3-1)

TABLES SHOWING VIRTUAL DIFFERENCE IN DIAMETER CORRESPONDING TO ERRORS IN PITCH AND ANGLE

TABLE 15

VIRTUAL DIFFERENCE IN EFFECTIVE DIAMETER CORRESPONDING TO MEASURED ERRORS IN PITCH

Error in Pitch	Corresponding Virtual Difference in Effective Diameter			
	Unified, Metric and B S C Threads	Whitworth Threads	B A Threads	Acme Threads
in	in	in	in	in
0·000 05	0 000 09	0 000 10	0 000 11	0 000 19
0 000 1	0 000 17	0 000 19	0 000 23	0 000 39
0 000 15	0 000 26	0 000 29	0 000 34	0 000 58
0 000 2	0 000 35	0 000 38	0 000 45	0 000 77
0 000 25	0 000 43	0 000 48	0 000 57	0 000 97
0 000 3	0 000 52	0 000 58	0 000 68	0 001 16
0 000 35	0 000 61	0 000 67	0 000 79	0 001 35
0 000 4	0 000 69	0 000 77	0 000 91	0 001 55
0 000 45	0 000 78	0 000 86	0 001 02	0 001 74
0 000 5	0 000 86	0 000 96	0 001 14	0 001 93
0 000 55	0 000 95	0 001 06	0 001 25	0 002 13
0 000 6	0 001 04	0 001 15	0 001 36	0 002 32
0 000 65	0 001 12	0 001 25	0·001 47	0 002 51
0 000 7	0 001 21	0 001 34	0 001 59	0 002 71
0 000 75	0 001 30	0 001 44	0 001 70	0 002 90
0 000 8	0 001 38	0 001 54	0 001 81	0 003 09
0 000 85	0 001 47	0 001 63	0 001 93	0 003 29
0 000 9	0 001 56	0 001 73	0·002 05	0 003 48
0 000 95	0 001 64	0 001 82	0 002 16	0 003 67
0 001 0	0 001 73	0·001 92	0 002 27	0 003 87

Note—The Difference is to be taken as + for external threads and — for internal threads

APPENDIX A(4-1)

I- METRIC

-General:

$$J = D4L/8 \quad (1)$$

-Acceleration torque (speed o to w):

$$Ta = 3w/t(JL + Js + Jm)/e \times 10^{-6} \quad (2)$$

-Equivalent inertia of load:

$$JL = wl\ p2 / 4000 \quad (3)$$

- Friction torque:

$$Tf = Fp/ 644e \quad (4)$$

-For a sliding system, frictional force·

$$F = us.\ WL \quad (5)$$

- Total motor torque·

$$T = Ta + T\ f \quad (6)$$

- Acc. torque (speed o to W):

$$Ta = 3.J.W/t \times 10^{-6} \quad (7)$$

Where:

J=moment of inertia , Kg-cm2.

D=diameter cm

L=length (or thickness),cm.

W=weight ,Kg.

Ta=acceleration torque, Nm.

w= max. speed, full steps/sec

t=time to reach w,secs

s=move distance, full,steps.

=total move time,secs.

II- IMPERIAL

-General:

$$J=WD4/8 \tag{8}$$

-Acc. torque :

$$Ta=Jw/7641 \tag{9}$$

-Acc.torque (trapezoid).

$$Ta=Js/170t \tag{10}$$

-Max. speed(trapezoid).

$$= 3s/2t \tag{11}$$

Where:

J=Moment of inertia,lb-ins2

D=diameter,in

L=length (or thickness), in.

Ta=acceleration torque, oz-in.

w=max speed, full step/sec.

t=time to each speed w,sec.

s=move distance, full steps

=total move time,secs

APPENDIX (A4-2)

Technical specification The " **medium duty** " motor

Type	5
r.pm at 12 vd.c.	8
Max. power (w)	4
Max . torque (m N m)	
continuous	600
peak	1800
Gear box reduction	500:1
Nom. voltage (v d. c.)	12
Starting voltage m,n	
no load (v.d.c)	0.15
Nom no load current	
(m A)	15
Max cot operating	
current (m A)	493
Terminal resistance (52)	10
Max rotor	
temperature (c)	85
Weight (g)	262

APPENDIX (A4-3)

- Technicals pecification of the " heavy duty " motor.

Type	2
rpm at 12 v d.c	20
Max. power (W mech)	16
Max.torque (m N m)	
continuous	1200
peak	4000
Gearbox reduction	130:1
Nom. voltage (v d.c)	12
starting voltage, min no load	3v
Nom. no load current (m A)	590
Max. continuous operating current (m A)	2800
Terminal resistance (o2)	2
Max. rotor temperature	130 c
Weight (g)	670

APPENDIX (A4-4)

Technical specification of the LVDT

type of (GT x 2500),

- Linear stork .. . . . . -+ 2.5 mm.
- O/P voltage .... 160 m v/v.
- Current LVDT .... 160 m A(6 m A).
- Linearity ... . 0 25% of fullstorke.
- Operation temperature .. . . -40 c to+ to 100 c.
- Weight (less cable).................... 18 g m
- Spring force . ... 118 g m

Figure (4-13), illustrates this sensor

APPENDIX (A4-5)

The technical specification of the Digital to Analog D/A converter type DAC-O2

Power suppliers:

+5V supply 75 m A type,100 m A Max.

-5V supply· not used

+12V supply: 15 m A typ. 1 25 m A max.

-12V supply: 25 m A type,35 m A max.

Total power dissipation typical.

Output ranges

Channels:2

I/o address :DIP switch selected on any 8 bit boundary.

Resolution: 12 bits (1 part in 4095)

Relative accuracy: 1/2 LSB (0.01%) max.

Differential linearity: 1/2 LSB max.

Fixed reference ranges. 0 to + 5V (unipolar)

0 to + 10V (unipolar)

+/-5 V (bipolar)

+/-10 V (bipolar)

4-20 m A current loap.

variable reference ingest: +/- 10 V (2 or 4 quadrant) reference input resistance : 7 known min, 11 kohm type, 20 kohm max. Voltage output impedance:<0.1 ohm max. Voltage output drive current: +/-5 m A min.

4-20 m A compliance : 8- 36 V   (for current loop)

Environmental

Temperature coefficient: +/- 25 ppM / deg.c. (with reference)

                of gain: +/- 5 ppM / deg.c. (external ref.)

Zero drift: 0-70 deg c.

Storage temperature :- 55 to + 125 deg.c.

Humidity :0- 95% non- condensing

Weight· 4 02 (120 g).

APPENDIX (A4-6)

The technical specification of the ANALOG TO DIGITAL (A/D) converter type DASH-8

-Resolution	12 bits. (2.44 m v/ bit)
-Full scale	+/-5 volts.
-Input current	100 n A max at 25 degree.c
-Sample and hold acquisition time	15 us for 0.01% error
-Reference voltage	+10.0 v +/-0.1 v
-Reference current	+/-2m A
-Digital output sink current	8.0 m A (Lo =.5 v)
-Digital output source current	-0 4 m A (hi= 2 7 v)
digital input high voltage	2.0 v min.
-Digital input low voltage	0.8 v max.

APPENDIX (A4-7)

The technical Specification of transducer amplifier

type S7M.

-Supply: 120 or a c. +/- 15% 50/60H2 at 2 5 v A

-Fuse: 200 mA A-5

-Excitation(note 1)· 5 v rim.5. 5 KHz sinusoidal (1KHz-10KHz to order).100m A max

Excitation Tempo ·+/-0 003%c. typical

Amplifier output1: +1/- 10 v 5 m A max (short-circuit proof)

output2·see options B and C specification below

Amplifier gain: x 03 to x 200 in 8 ranges

Linearity : +/- 0.1% of full scale max.

Demodulator : synchronous.

-zero tempo: +/- 0.002% f.5/c. typical.

-Gain tempo. +/-0.002% f.5/.c. typical.

-Bandwidth. flat to 500 h2.

-Output noise : 5 m v p.p typical(pK-pK)

-Input option z : 10 ohm differential

-Zero adjustment range . +/- 10 v minimum

Temperature range .10 to + 50c

Dimensions (excluding cable glands). 8 7 x 4 75 x 3.25 in (220 x 120 x 81 mm)

Weight : 3 3/4 Lb, 1 7 kg

-Physical protection .I p 65 specification

-Gland cable diameter (notes2): 0.08 to 0.2 in (2 to 5 mm) [63]