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Statistical process control for high precision deep drawn sheet metal parts

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ABSTRACT

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Drawn Sheet Metal Parts

Sunil Shah, Master of Science, Manufacturing Engineering, 1990

Thesis directed by: Dr. Keith O'Brien
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In today's world, industrial expertise has come to be judged in terms of the quality of the product. Good quality has become the ultimate aim in a manufacturing environment, which leads to many innovations for ease in the inspection of parts. In considering a metal working company like Hudson Tool & Die Company, a study of the various operations and the application of Statistical Process Control to the forming operations is performed using STORM software. Important characteristics have been carefully studied with regards to metal forming like uniform metal thickness, radius of the bend, depth of the drawing operation. In-depth analysis was performed on the pattern, and the cause of the variations. Various control charts such as average chart, range chart and **p** chart were obtained and different processes were studied. Computer aided quality control is fast becoming a standard in the manufacturing world. Non-contact gaging, coordinate measuring machines, and automatic conversion of the data into useful information are noteworthy and hence have been mentioned.

STATISTICAL PROCESS CONTROL FOR HIGH PRECISION DEEP DRAWN SHEET METAL PARTS

by
Sunil S. Shah

Thesis submitted to the Faculty of the Graduate School of
the New Jersey Institute of Technology in partial fulfillment of
the requirements for the degree of
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1990

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CHAPTER I THE NEED AND FUNCTION OF INSPECTION IN INDUSTRY

A. Multiple functions of the inspection department

Measurement is the most important function of industrial inspection. Inspection and measurement are no longer only concerned with accepting and rejecting parts, but also with supplying information, which can be used to improve quality and increase competitive performance.

The basis of inspection lies in understanding customer requirements, and the translation of those requirements into objectified measurements that can be carried out in the manufacturing arena. Figure 1 shows the basic inspection process.

The quality balance of acceptable versus unacceptable detail in a product, component, or even a manufacturing process is indeed the responsibility of the inspector. Inspection, therefore, must:[1]

1) assure that the operating organization has performed its functions properly; and

2) provide adequate safeguards against the shipment of defective products. This may be accomplished by 100% or "detail" inspection. The same purpose may be accomplished by reaching a decision to accept or reject the product after examining only a part of it. This is called sampling inspection.

The inspector must understand and interpret according to objective criteria or specifications in an inspection. To assess the level of change in a component, product, or process from acceptable variation to excessive variation, is the responsibility of the inspector. If the variation is deemed acceptable, the inspection is either continued to insure on-going compliance with the requirements, or the inspection sequence is completed. If the measured variation is unacceptable, then other variables such as time or personnel are factored into the results and considered as a possible cause of excess variation.

Cost, of course, plays an important role in balancing the quality scale. It is important to understand whether the changes, improvements, or reductions in variation are cost-effective or not. The cost of inspection is usually small in comparison with the total cost of a product. Nevertheless, inspection procedures can have an important effect not only on the cost inspection but on the cost of manufacture as well. Management groups for manufacturing systems are charactered with this important and delicate decision. What is important to the customer, and how much will he pay for these requirements and performance levels are the criteria for relevant inspection detail.

Part of this inspection cycle, which involves awareness, assessment, reporting, and acting, includes the education of other production, or manufacturing personnel. Ultimately, responsibility for the inspection of parts, components, and the finished products lies with the person who produced them. An adequate translation of customer requirements through specifications and product criteria must be available to production employees. Therefore, the work of inspection personnel is much more broad than that of making the direct measurements.

A portion of manufacturing inspection frequently overlooked is the responsibility for making sure that the correct materials have been used and especially that all of the processing operations have been performed.

In order to institute extensive levels of responsibility for manufacturing quality and performance, an inspection system must be far-reaching within the organization and have excellent communication abilities. Inspection must constantly interact at many levels with the process and systems it is measuring on a continuous basis, in order to insure that the results of inspection are fully understood, and integrated within a system that strives for constant improvement.

The subject of inspection methodology, or inspection procedures, is an extensive and rapidly changing field of application. Industrial competition is driving inspection to make better, and more accurate, decisions with less direct inspection, at decreased costs. Today, the prevention of problems or nonconformances, is deemed more important in industry than the detection of defects.

In many cases inspections may involve testing and gaging combined. In a functional test, the product is actually used, run, worked, or stressed at inspection, under the same conditions as in end use. Whatever the test used or the method of assessment that is employed, it must reflect the criteria that are being evaluated, and these criteria must be what the customer wants to buy, at the right cost. The need and function of inspection in industry is shown on figure 2.

Whatever type of inspection is used, whether it be a complete manual, or automatic gaging setup, or whether the inspection is a simple visual assessment, it is important to have an organized proven plan for the inspection. In addition, one must follow it as long as it serves the needs of the appropriate inspection.

B. Off-line and on-line inspection

The timing of the inspection procedure in relation to the manufacturing process is an important consideration. Three alternative situations can be distinguished: [2]

1. Off-line inspection
2. On-line/in-process inspection
3. On-line/postprocess inspection

An off-line inspection is performed away from the manufacturing process, and there is generally a delay between processing and inspection (See figure 3). Most manual inspection fall in this category. Off-line inspection usually involves a statistical sampling procedure. The disadvantage of off-line inspection is that the part have already been made by the time any poor quality is detected.

The alternative of off-line inspection is on-line inspection. This is an inspection procedure that is performed as the parts are being made. The two on-line inspection procedures can be distinguished as on-line/in-process and on-line/postprocess inspection (See figure 4).

On-line/in-process inspection is achieved by performing the inspection procedure during the manufacturing operation. With on-line/postprocess inspection, the measurement or gaging procedure is accomplished immediately following the production process. Even though it follows the process, it is still considered an on-line method because it is integrated with the manufacturing workstation and the results of the inspection can immediately influence the production operation.

C. Inspection records

Whenever possible, measurements or inspections should yield a result that is understood quantitatively-through the use of numbers. The description should include a number that is referenced against a standard unit of measure.

Quantitative measurements are described as variables data-numbers and offer more tangible information in an inspection than would a qualitative assessment of a component or a workpiece. These qualitative assessments are called attributes. An attribute's characteristics can only be qualified by words, not numbers and as such do not contribute as much concrete information as a dimensional measurement.

Many industries have measurement problems. Gages and operators add to the problems. How are parts measured with a snap gage? How is "feel" taught to an operator, and how is consistency between operators developed? Are the gages recalibrated periodically? Are statistical process control charts reliable when the measurements are in doubt?

There are two sets of problems here. One involves techniques for checking gage accuracy and precision, the other involves management records control.

Accuracy is a matter of correct calibration. It refers to the absolute correctness of the measurements as compared with some known standards. With tool room or laboratory conditions and skilled technicians, accuracy can be determined. Precision is the ability of a gage to deliver accurate readings repeatedly, when used by same or different operators. It refers to the reproducibility of the measurements.

A treatment of inspection should include a study of instrumentation gages, meters, special apparatuses, visual aids, and their selection, manipulation, and maintenance. In today's quality conscious industry, most manufacturers have inspection facilities to inspect their own tooling and production gages and to determine if purchased parts meet specifications. But with close tolerance gages, it is difficult for the manufacturers to determine the extent of calibration necessary.

A comprehensive treatment of inspection should include a study of the more commonly used industrial inspection routines, the planning of an effective day's work, the keeping of essential records, and the elimination of unnecessary activities. A well designed system maintains different kinds of information for each gage identifying it, recording its history and scheduling future activities. Each gage requires one master record, including gage name, type, manufacturer, cost, serial number, customer, part number, tolerance range, physical location, and the latest test results.

The particular factory or production control number should be recorded. This might be termed a "lot" or "batch number". It is also good practice to note the time of day of the inspection. Sample size, in terms of the units inspected and the number contained in the lot or batch itself, is critical in maintaining usable inspection records. From this information, process performance and product quality levels can be deduced. Numbers are critical to the proper assessment of systems and processes; if the "raw" numbers are accessible in inspection records which document the number of parts inspected and the population size, number defective, and number of defects, then more advanced statistical interpretation of the results centering around such mathematical applications as average, range, and standard deviation, can be accomplished.

One other step, in addition to making an accurate inspection record is to make an accurate and comprehensive record in connection with each receiving transaction. As a detail in making receiving inspections and records, it is important to distinguish between original vendor manufacturing defectiveness and defectiveness caused by packing, shipping, receiving, and careless handling.

CHAPTER II A COMPUTER-AIDED APPROACH TO MANUFACTURING QUALITY

A. Introduction to computer-aided quality control

Many of America's industries have undergone a renaissance in thought regarding quality. The traditional production process in which an inspection or quality control group sorts the good product from the bad cannot be tolerated. Instead, manufacturers must have dependable process to produce uniform products that meet customer needs and expectations. The design and manufacturing processes must change to assure process capability.

An organization that gets involved in quality improvement will face two challenges:

1. Instead of trying to improve product quality, it must concentrate on improving the quality of the production process.
2. The company must assure ongoing quality improvement throughout the organization. This includes not only manufacturing, but also administrative areas such as finance, marketing, and personnel.

With its renaissance in thought, American industry has taken various steps to address these challenges. The approach often begins with the management philosophy of a quality expert such as Dr. W. Edwards Deming, Dr. Joseph M. Juran or Philip B. Cosby.

The concepts of these three quality experts provide road maps for companies to establish a quality culture. Although the routes they suggest differ somewhat, their destination is the same: world-class quality.

Adoption of automation by US manufacturing industries is just beginning, and to the degree that Computer-Integrated Manufacturing(CIM) technologies are being adopted, attainment of "conformance quality" is the main reason. Quality has both an internal and an external focus. The internal focus is on raising material, machine and labor efficiencies and doing it right the first time. The external focus is on consistently meeting customer expectations. There has been a change in philosophy from tolerance-based quality to target-based quality as a key factor in vendor selection. The ultimate goal of both orientations is to make the manufacturer a low-cost producer of high-quality products.

This goal cannot be achieved without adequate control of the manufacturing process. The goal of automation is to either maintain or improve product quality while reducing product cycle time in an unattended manufacturing environment. The capability of producing defect free products hinges on a number of parameters, inspection being one of the critical ones. But there is, of course, a major distinction between post-process inspection and defect prevention (See figure 5). Effective computer-aided quality control of the manufacturing process begins with the acquisition of shop floor data. To achieve real time process control, the vital ingredient is process data obtained via in-process measurement. Manufacturing data can be acquired on items such as the correct location of mounting holes in an engine block to the consistent operation of a limit switch. Data can help trace the manufacturing history of a product or a point to potential problems in the manufacturing process. This postprocess approach has one big flaw-lost value. By the time a bad part is identified, all of the "value" intended for it has been committed-machines, labor, material, electricity and rent. That lost "value" is expensive.

Most of the quality control effort in the metal working industry is after the fact. During a production run, a part is fixtured, machined and then inspected. If within tolerance, it is accepted and the production run continues. If the part doesn't meet spec, it is rejected, the machine is stopped and corrections are made.

New developments in electronic gaging are changing the emphasis from simple open-loop, post-process quality control to automated, closed-loop interpolation quality control. The essential feature of the quality system is that corrections are made during the batch run. Data are the raw ore of quality. Manufacturers can use data that is already available on the plant floor as a means of improving process quality and for verifying that the customer requirements have been met. There is a big difference between data and information: before data can be used for effective decision making on quality and corrective feedback, it must be refined to allow the rapid conversion of data into information.

B. Automated inspection

Automated inspection equipment for gathering information is one of the main elements required to achieve the goal of making quality parts at minimum cost. Due to the importance of the inspection and quality data collection functions in automated systems, the planning for this function must not be left to chance. Computerized system offers tools to capture data, convert it into information, package the information into useful forms and distribute it throughout the factory. Thus providing the facts, figures and analysis manufacturers need to keep their processes under control are supplied. In the automated factory, the inspection system must have the same degree of flexibility as the machine tools that make the parts. As the number of different parts being made increases while the lot sizes remain small, flexible stand-alone machines come into use. As the lot sizes grow while the variety of parts remain small, dedicated transfer-type machines come into use. In this case, machines perform a wide variety of operations in multiple stations on a small number of different parts. The task of integrating inspection into the manufacturing process is complex and must be addressed in the early stages of planning for an automated manufacturing systems. Flexible Manufacturing Systems (FMS) are currently being used to make a moderate number of different parts in moderate lot sizes.

Over the next few years, the application of FMS for new facilities is expected to expand. To support the foreseen growth of FMS, the integration of the Flexible Inspection Systems (FIS) must be included in the initial planning of the manufacturing system. A flexible inspection is defined as a highly automated inspection workcell consisting of one or more coordinate measuring machines and other types of inspection equipment, plus the parts handling systems needed to move parts into, within, and out of the cell (See figure 6). The trade offs between the cost of inspection equipment and those related to machine cycle time, in-process inventory, scrap, rework and part shortages must be carefully weighed against the value of having workpiece quality data that is produced by independent devices designed specially for that purpose.

C. Types of sensors

There are a variety of sensor technologies available divided into two broad categories:

1. Contact inspection methods
2. Noncontact inspection methods

Contact inspection involves the use of a mechanical probe or some other device that makes contact with the object being inspected. Contact methods are usually concerned with some physical dimension of the part and predominantly used in mechanical manufacturing industries. Prominent among the contact inspection machines are coordinate measuring machines.

Noncontact inspection methods involve a sensor located at a certain distance from the object to measure or gauge the desired features. The potential advantages offered by noncontact inspection include lower inspection times and avoidance of damage to the part that might occur from contacting it.

D. Coordinate measuring machines

A coordinate measuring machine is a general purpose machine that can be used to inspect a variety of different part configuration with minimal changeover time. It consists of a contact probe and a means of positioning the probe in three dimensional space relative to the surfaces and features of a workpart.

In the construction of a coordinate measuring machine, the probe is fastened to some type of structure that allows movement of the probe relative to the part. The bridge configuration shown in figure 7 is the most common type used in industry.

The positioning of the probe relative to the part can be accomplished either manually or under computer control. The methods of operating and controlling a coordinate measuring machine can be classified as follows:

1. Manual control: In manual control method, the human operator physically moves the probe along the machine's axes

to make the contact with the part and record the measurements. Any calculation on the data must be made by the operator.

2. Manual computer assisted: This method provides some level of computer data processing and computational capability for performing the calculations.

3. Motorized computer assisted: The motorized computer assisted coordinate measuring machine uses a motor drive to power the probe along the machine axes under the operator's guidance. The motor drive can be disengaged to permit the operator to physically move the probe as in the manual control method.

4. Direct computer control (DCC): The direct computer control coordinate measuring machine is motorized and the movements of the coordinate axes are controlled by the computer. The computer also performs the various data-processing and calculation functions, and compiles a record of the measurements made during inspection. It is highly automated inspection machine that operates under program control.

E. Types of automated inspection

The options for workpiece inspection in the automated factory fall into four areas:

1. Deterministic metrology, in which various parameters of the machine tool itself are monitored during the machining cycle. It can spot trouble before it causes any problems,

and can be used to identify the sources of error within the machine tool prior to the production of rejects.

2. On-machine gaging, in which the workpiece is monitored during the machining cycle to validate and control the process. It is particularly appropriate for checking a limited number of features for the dimensional errors.

3. Post-process inspection, in which the workpiece is inspected using special sensors while it is still on the machine tool, but after the machining operations are complete. It requires the least capital investment. Like the other on-machine inspection techniques, it minimizes the amount of part handling involved with the inspection process. It is dependent on the accuracy of the machine tool itself. Systematic errors in the machine tool can go undetected.

For accurate inspection data, the work must always be completely cleaned thus allowed to achieve thermal equilibrium within the environment of the inspection equipment. In the case of on-machine inspection techniques, these requirements for accuracy will affect productivity since the machine tools cannot be making parts while a part is being cleaned and allowed to cool to prepare it for inspection. In the case of independent inspection equipment, these steps can be performed while the parts are in the inspection queue.

4. Independent inspection, in which the workpiece is inspected after it leaves the machine tool, by means of an automated inspection system totally dedicated to this task.

This is a completely automated and computer-controlled inspection system with the same degree of flexibility as the processing equipment it supports. Flexible coordinate measuring machine (CMM) are equipped with a probe changer, automatic workpiece loading and unloading, a means for identifying workpieces, access to a part program library, and a communication link with the host computer. The use of these systems helps to optimize the throughput of the automated factory. They provide quality control data that is completely independent of the machining processes and can be used to validate the entire manufacturing process.

The basic philosophy for workpiece inspection must be to use traditional contacting methods whenever applicable. Noncontacting methods should be used only if a problem cannot be solved by contacting means.

F. Distinction between data and information

Computer based information in the manufacturing environment can take on as many forms as there are needs. The information can identify process trends that threaten product quality. Information in the form of statistical process control tools such as scatter plots, histograms and control charts help plant personnel achieve zero defect performance. Trend charts for machine performance help personnel observe the quality of a process, which in turn helps them prevent unscheduled downtime and establish cause and effect relationships between process and machine faults. The potentials of application are limitless.

The computer-aided real-time conversion of manufacturing data into hard-hitting, usable information is a complex task. It can require programmable logic controllers(PLC), supervisory level controllers, sophisticated operator interface devices, communications network and advanced software. It can also require the interface and/or the integration of plant floor computing with other areas of the company such as engineering and material resources planning.

A logic control system is a switching system whose output at any moment is determined exclusively by the values of input. A modern control device used extensively for process control is the programmable logic controller. Input/output modules of programmable controllers are not only capable of monitoring the status of the process sensors, turning switches on and off and regulating the flow of a liquid, they also can acquire data on the relative performance of the process.

It is with these computer-based systems-programmable controllers, electronic operator interface devices, machine vision systems, communication networks and the like, that industrial control suppliers can assist their customers in achieving zero defect performance.

The trend toward vendor quality certification grows each year. Most certification program require documentation on process control and capability using SPC charts. Computer-aided quality systems cost-effectively produce this documentation, as a by-product of the control system.

Manufacturers armed with this information will be able to differentiate their products from the competition, demonstrate their commitment to quality, and prove that they have value-added products, and thus increase their market share.

CHAPTER III INTRODUCTION TO STATISTICAL PROCESS CONTROL

A. Meaning of the term Quality

"Quality" means different things to different people. Quality represents something that can be measured and evaluated. The word quality has come to have a variety of meanings in addition to "fitness for use". The generally accepted definition of quality is "The totality of features and characteristics of a product or service that bear on its ability to satisfy given needs". [3]

The Quality Conformance is how well the product conforms to the specifications and tolerances required by the design. Quality of conformance is influenced by a number of factors, including the choice of manufacturing processes, the training and supervision of the work force, the type of quality assurance system used, the extent to which these quality assurance procedures are followed, and the motivation of the work force to achieve quality.

B. Current trends in Quality control

Quality has emerged as a major new business strategy. This has happened for a number of reasons, including:

1. Increasing consumer awareness of quality and strong consumer quality performance orientation.
2. Product liability.
3. Increasing cost pressure on labor, energy, and raw materials.

4. More intensive competition.
5. Dramatic improvement in productivity through effective quality engineering programs.

In order to assure quality components, assemblies, and processes, three engineering functions- Design, Manufacturing, and Quality Assurance must work together in the planning stages of product design, tooling, and inspection. Each in turn must relate to one another's responsibility so as to create a total system which will have high reliability.

Manufacturing of fabricated components, chemical product, and metallurgical products should all be considered processes. The specifications can take different forms.

Measurement at each step in the manufacturing operation should exhibit a normal distribution. The measurement and display of information should be as close to the operator as possible and the operator should be held responsible for building quality into the product. It cannot be inspected after the product has been made.

In all systems, there are some attributes that are more critical to product performance than other attributes. It pays to plan the processing of critical parameters with greater care and to monitor these parameters more closely in the shop. Tolerances should be checked with the process capability. Controlling quality in the factory requires a thorough analysis of the product. In the case of the processes, the process parameters can be extremely critical.

In order to maintain normal distribution, feedback in the machine control cycle can be incorporated. But every shop does not have the volume to justify such parameters.

Quality integrity is the result of line and staff dedication to the control of incoming material, control of manufacturing operations, control of tooling and equipment, and control of inspection gauges and testing facilities. A Quality Assurance program reviews all functions within the organization which contribute to the product or service fulfilling its expected requirements. It is essential that a Quality Assurance program is very closely integrated throughout the organization to ensure that all parties are contributing, and that no responsibilities are omitted.

C. Process and statistical control of a process

Statistical Quality Control (SQC) can be categorized into four steps of control in order to implement it: [4]

1. New design control;
2. Incoming material control;
3. Product and process control;
4. Product quality, reliability and safety assurance control.

Quality Control can be defined as "The entire collection of activities through which we achieve fitness for use". It is a science that uses quantitative and qualitative methods to make decisions that affect the quality of manufactured products. These methods simply provide the tools to analyze the information at hand in order to make accurate decisions.

Quantitative methods include that group of techniques which allow engineers to make decisions based on numbers. These methods, in many instances, require statistical treatment of the data. Statistics is the collection, organization, analysis, interpretation, and presentation of data. It is just one of many tools necessary to solve quality problems. The objective is to make a quality product and not to promote the statistical method as an end in itself.

Taken together and applied to a manufacturing operation; the words statistical quality control means: [5]

STATISTICAL - With the help of numbers, or data

QUALITY - Study the characteristics of process

CONTROL - In order to make it behave the way expected

Statistical Quality Control is the control of quality during the production process using the statistics of probability to determine and maintain the state of statistical control - the capability of process (See figure 8). Statistical analysis requires the measuring of the process output, preferably quantitatively, and the generating of an adequate amount of data to provide statistical significance. A minimum of 12-15 measurements on consecutively produced items is required in order to calculate the standard deviation, which is a piece of knowledge necessary for statistical capability measurement.

A "process" is any set of conditions, or set of causes, which work together to produce a given result. Product and process control is the control of a product from its initial manufacture, through to the final product utilizing feedback from the processes, fabricating the final product and from input from the field (See figure 9). The main objective is to correct any deviation of a product or part from specification before it becomes defective. The broadest application of statistics to industry in the U.S. has been in the application of sampling to determine lot quality. Sampling requires establishment of AQL's (Acceptance Quality Levels), AOQL's (Average Outgoing Quality Limit), and LTPD's (Lot Tolerance Percent Defective). When lot quality does not meet these requirements, screening is a conventional method to improve lot quality. At one time, acceptable quality levels (AQLs) and percent defectives were acceptable in the U.S. Now suppliers are required to ship defect-free parts or defects in less than 200 parts per million. By applying Statistical Quality Control to processes, the Japanese are experiencing PPM (one defect per million part). Today Statistical Process Control has become an integral part of manufacturing philosophy. Any process has two causes of variation: special and common. Special causes are usually considered excessive variation and are assignable to specific process deviations. They can be readily identified by control charting the process and/or through diagnostic inspection of the product. A process exhibiting special causes is not in statistical control. The main characteristics of process control are improved stability and reduced variability. Through conscientious monitoring of manufacturing processes, process changes that produce bad parts can be predicted and the process corrected before an operator produces bad parts. Thus quality should be obtained by inspecting the process rather than the product.

Global competition is forcing many manufacturing companies to shift from defect detection to defect prevention which forces inspection out of the quality assurance laboratory and onto the manufacturing floor to provide timely feed back for process control and process correction. Mr. John Bosch, president of Sheffield Measurement, cites eight kinds of costs that can be sharply reduced by a change to on-line inspection. [6]

1. Scrap losses. Lack of timely feedback precludes process adjustment to avoid producing out-of-spec workpieces.
2. Rework costs include re-machining and re-inspecting as well as lost income from machine time devoted to rework.
3. Machining center downtime while awaiting first part inspection to verify machine setups.
4. Staffing costs to run inspection routines manually instead of creating an inspection program on a one-time basis.

5. Material handling in sorting and delivering samples from the shop floor to the inspection area.

6. Greater in-process inventories from samples waiting to be inspected before the batches can be released.

7. Final assembly difficulties from non-conforming parts that are not rejected. Final inspection must be emphasized.

8. Warranty and liability claims from product failures and shortened wear life, and so on.

The rewards of good product and process control is minimizing internal and external failure cost and maximizing customer satisfaction, which leads to minimizing the possible liability posture of a company. The type of control utilized depends on the type of manufacturing done, the inherent control of the process and the risk involved with failure. An inherent and integral gradient of control is not only the process, but also the operator controlling the process.

William Scollard, Vice-President of Ford Motor Co.,(Dearborn, Mi) concludes that: [7]"Technology no matter how sophisticated, is useless if it outstrips the abilities of people to understand, implement, and manage it. Employees must be given the skills to use new tools such as Statistical Process Control(SPC), Team-Oriented Problem Solving(TOPS), and Quality Functional Deployment(QFD)".

CHAPTER IV UNDERSTANDING VARIATION AND CONTROL CHARTS

A. Understanding variation

As a starting point for understanding the concepts of common and special causes of variation, it is useful to review the notions of processes and systems. A process can be defined as a set of causes and conditions that repeatedly come together to transform inputs into outcomes. The inputs might include people, materials, or information. The outcomes include products, services, behavior, or people. A system is an interdependent group of items, people, or processes with a common purpose. For manufacturing processes, examples are quality characteristics such as length, width, viscosity, color, temperature, line-speed, number of accidents, and percentage of rejected material.

The source of variation in a process can be found in one or more of five areas: [8]

1. Materials;
2. Machine;
3. Methods;
4. Operators;
5. Environment (See figure 10).

A fundamental concept for the study and improvement of processes or systems developed by Walter Shewhart is that variation in a quality characteristic has two types of causes.

1. Common causes: those causes that are inherently part of the process (or system) hour after hour, day after day, and affect everyone working in the process. Common causes produce natural variation. In this case, a product will vary in a normal, predictable manner. The process is said to be stable.

2. Special Causes: those causes that are not part of the process (or system) all of the time or do not affect everyone, but arise because of special circumstances. Special causes produce unnatural, avoidable variation.

A process whose outcomes are affected by both common causes and special causes is called an unstable process. An unstable process does not necessarily have large variation. It is termed unstable because the magnitude of variation from one time period to the next is unpredictable.

From the above theories of variation, the following can be said about the activities to improve quality:

1. Leadership by top management will be needed to insure that everyone in the organization is given the appropriate responsibilities for improvement.

2. To improve quality, the primary role of workers in the process is to identify special causes and remove those that they can not control.

3. If workers are not trained in the use of basic statistical methods and are not given time to identify special causes, technical experts will have to perform this role.

Quality control is as old as industry itself. From the time man began to manufacture, there has been an interest in quality of output. As far back as the Middle Ages the medieval guilds insisted on a long period of training for apprentices and required that those seeking to become mastercraftsmen offer evidence of their ability.

Statistical control is new. The science of statistics itself goes back only two to three centuries, and its greatest development has been in the last sixty years. A factor in the birth of statistical quality control in the Twenties was the development, in immediately preceding years, of an exact theory of sampling.

In industry, the theory of probability is frequently used in connection with sampling. A very concise definition of probability is that it is a relative frequency. It is a relative frequency that retains to specially defined circumstances.

A decision regarding the acceptance or rejection of a lot may be based on the inspection of a sample from this lot. If the theory of probability is to be properly used to calculate the risk of a wrong decision resulting from the analysis of such sample data, it is required that the sample be random.

The general rules to be borne in mind in drawing a random sample are:

1. Adopt a method of selection that will give every member of the universe an equal chance of being drawn.

2. Avoid any method that associates the selection of an item with the classification of the item being selected.

One of the most important problems facing anyone concerned with quality improvement is that all processes, no matter how well controlled, exhibit variation. The variation has as its source literally dozens of potential causes.

Process evaluation involve a study of methods used to produce an end result. Process performance can usually be best evaluated by statistical methods, and it is becoming common to require that statistical process control be applied to critical process characteristics.

The first to apply the new statistical methods to the problem of quality control was Walter Shewhart of the Bell Telephone Laboratories [9]. In a memorandum prepared on May 16, 1924, Shewhart made the first sketch of a modern "control chart". In addition to providing the basic concepts, Shewhart also provided a method to determine whether variation in a process is dominated by common or special causes and whether the variation can be avoided or not. This method is the Shewhart control chart.

A central concept in statistical process control is that almost every measurable phenomenon is a statistical distribution. There are three basic properties of a distribution: location, spread, and shape. A distribution can be characterized by these three parameters. The location refers to the typical value of the distribution.

The arithmetic mean is a commonly used measure of location. If the data are continuous and arranged in a frequency distribution with class intervals, the mean may be computed by multiplying the mid-point of each interval by the frequency of the interval, adding, and dividing by the sum of the frequencies. A histogram is nothing more than a frequency distribution put into block form (See figure 11). It is one of the tools that helps keep track of variation. It shows how many pieces are for each measurement.

The spread of the distribution is the amount by which smaller values differ from larger ones. The standard deviation and variance are measures of the distribution spread.

The simplest measure of general variability is the range. It is the difference between the highest and the lowest value of a set of data, and is represented by R.

A more commonly used measure of general variability is the standard deviation. This is defined, as the square root of the average of the squared deviations from the mean. The square of standard deviation is called variance.

By far, the most common continuous distribution encountered in quality control work is the normal distribution (See figure 12). The normal distribution curve is sometimes called the bell curve because of its shape. The curve is said to be symmetrical. Figure 13 shows relationship between a control chart and normal distribution.

In America it is common to use a limit as three times the standard deviation. The decision would in any case depend on the management of the quality control program wished to run.

If sample values of measurements are plotted for a significant range of output and time and these values all fall within the control limits and show no cycles or runs above or below average or runs up or down, then it can be said that the process is in a state of statistical control at the level designated with respect to the given measure of quality.

If the output of a process is inspected 100 percent, then the sample of output that occurs in given time frame may be the sample taken for control-chart purposes. In this case the sample size is determined by the rate of production and will vary from period to period. If a control chart is based on a sample especially selected for control purposes, both the size of the sample and the frequency of sampling will have to be determined by the control authorities. Large samples taken at short intervals, would, of course, give the best protection against shifts in the process, but this becomes expensive. A complete solution of this problem would require knowledge of the costs involved in not catching shifts when they occur and costs connected with the amount and frequency of the inspection process.

B. Average and Range charts

Control charts based upon measurements of quality characteristics are often found to be a more economical means of controlling quality than control charts based on attributes. Average charts are statistical tools used to evaluate the central tendency of a process over time. It shows whether to make no adjustments and inherent variation appears, or to correct the process because of assignable variation. An average chart shows variation in the averages of samples. Range charts are statistical tools to evaluate the dispersion or spread of a process over time. An R-chart shows variation in the ranges of samples. On it is a central line and an upper and lower control limit. If the chart is being used to analyze past data, the central line will be the average of the sample ranges.

C. Preparation and analysis of Average and Range charts:

1. The subgroup size and sampling frequency must be determined. Typically, subgroups of four to six units are sufficient and subgroups of five are most common. The subgroup size affects the sensitivity of the control chart. Smaller subgroups give a control chart that is less sensitive to change in the process, while larger subgroups are too sensitive to small, unimportant changes. Sampling should be frequent enough to detect the effect of special causes while the special cause itself can still be identified.

2. Data is collected from 20 to 25 subgroups; at least 100 individual values are recommended.

3. The necessary calculations are performed.

4. Interpretation of control charts is done. The interpretation of control charts for the average and the range involves two considerations: freaks and non-random patterns. Either case represents the presence of a special cause of variation. Freaks are detected by comparing each individual subgroup average and range to the control limits computed.

5. The greatest use of control charts is to demonstrate that the process is operating statistical control, but is still producing parts that are out of specification. When this happens, it is a waste of time to try to find a solution to the problem by adjusting the process. The existence of a nonrandom pattern means that a special cause of variation is present. When a point responds to an out-of-control test it is marked with an "x" to make the interpretation of the chart easier. Using this convention, the pattern on the control charts can be used as an aid in troubleshooting.

Average and range charts are used for jobs where there are unsolved engineering problems and cases where it is expensive to obtain data, as in destructive testing.

After average and range charts have shown that a process is in control, a study of process capabilities is often undertaken. This is to find out whether the process can meet specifications; and, if not, to estimate the fraction which is defective.

D. Control charts for percent defective (p charts)

This type of chart is used where a dimension, or characteristic is not measured in numbers, but is considered either "good" or "bad". A percentage is the number of units out of 100 units that are defective. "**p** charts" are statistical tools used to evaluate whether the proportion nonconforming parts produced by a process demonstrates a state of statistical control. The center line on the chart is an estimate of the fraction defective of the process. The p and np charts use attribute or counting data. The **np** chart gives number of defective parts in the sample.

E. Preparation and analysis of p charts:

1. The sampling frequency is determined. Sampling should be frequent enough to detect the effect of special causes while the special cause itself can still be identified.
2. Data is collected from 25 to 30 subgroups.
3. The control limits are established and necessary calculations are performed.

p charts are used in the cases where it is desired to reduce repairs, scrap, and rework, and the causes for these are known to , or controlled by the operating group. It is also used in the cases where some means of detecting assignable cause is needed and it is not economically feasible to obtain variables data for average and range charts.

F. Machine and process capability

Once the assignable causes have been eliminated from a process or operation, it becomes stable. The next step is to analyze whether the machine or process is capable of producing the parts within the specification or not.

A machine capability study is performed on a single machine or operation with one dimension of a product at a time. The measurements used to measure that capability should show only the variation caused by the machine and not by other parts of the process such as the operator, the material, or the environment. One purpose of the study is to make an estimate of the average dimension produced by the machine or operation. A second purpose of the study is to make an estimate of how the dimension is clustered around the average. Average and range charts are two ways to measure the capability of a machine or process and to compare it to the product tolerance. Figure 14 shows comparison between a process capability study and a process control chart. The capability of machine or process can be described by the capability index. This is a handy way to talk about the capability of any machine or process. The capability index is simply the ratio of the specification spread or tolerance to the machine or process spread, or six standard deviations of the process.

The first step in using the information from a process capability study is to see whether the capability, as revealed by the study, is inside of specifications. A process may be in control but at an entirely wrong level. It might be in control and still be 50% outside of specifications. It might be in control but have a wide spread. Action of some sort is required as a result of study. The required action may be:

1. Action on the process
2. Action on the data
3. Action on the specification.

The total variation in the process is separated by control charts into natural and unnatural portions. The unnatural portion is then studied for the purpose of identifying and eventually removing its causes (See figure 15). When these causes are removed the process is reduced to its true capability.

CHAPTER V QUALITY CONTROL OF METAL FORMING PROCESSES

A. Introduction

In a manufacturing process, a given material, usually shapeless or of a simple geometry, is transformed into a useful part. This part usually has a complex geometry with well defined shape, size, accuracy and tolerances, appearances and properties.

There are five main characteristics of any manufacturing process- namely geometry, tolerances, production, and human and environmental factors. The manufacture of metal parts and assemblies can be classified into five general areas.

1. Primary shaping processes, such as casting, melt extrusion, die casting, and pressing of metal powder. In all these processes the material initially has no shape but through the process obtains a well defined geometry,
2. Metal forming processes, such as rolling, extrusion, cold and hot forging, bending and deep drawing, where metal is formed by plastic deformation,
3. Metal cutting processes, such as sawing, turning, milling and broaching, where a new shape is generated by removing the metal,
4. Metal treatment processes, such as heat treating, anodizing and surface hardening, where the part remains essentially unchanged in shape but undergoes change in shape,

5. Joining processes, such as welding, diffusion bonding, mechanical joining as riveting , shrink fitting, where two parts of the same or different metals are joined together.

B. Metal forming processes

In metal forming, an initially simple part, for example a billet or a sheet blank is plastically deformed between dies to obtain the desired final configuration. Forces are applied to the sheet metal blank to cause permanent change of contour. Metal forming processes usually produce little or no scrap and generate the final part geometry in a very short time, usually in one or a few strokes of a press or hammer. During forming, one area of the blank is usually held stationary on the die as the punch forces the other area up or down to complete the change in contour. A given shape of a workpiece is converted to another shape without change in the mass or composition of the material of the workpiece. For a given weight, parts produced by metal forming exhibit better mechanical and metallurgical properties and reliability than do those manufactured by casting or machining. There are various forming processes such as rolling, extrusion, cold and hot forging, bending and deep drawing, where metal is formed by plastic deformation. Metal flow is influenced mainly by-

a) Tool geometry;

b) Friction conditions;

c) Characteristics of the stock material;

d) Thermal conditions existing in the deformation zone.

The details of metal flow influence the quality and properties of the formed product and the force and energy requirements of the process.

The metal flow, the friction at the tool and material interface, and the heat generation and transfer during plastic flow are difficult to predict and analyze. In metal forming, friction is usually controlled by boundary lubrication. A lubricant reduces the sliding friction between the dies and the workpiece. It also acts as a parting agent and prevents sticking of and galling of the workpiece to the dies. In metal forming processes the forming loads and stresses depends on part geometry, friction and the properties of the deforming material. Formability of the material to deform without failure depends on

1. Conditions existing during deformation processing such as, temperature, forces, stress, and strain, rate of deformation, and;
2. material variables.

The characteristics of sheet metal forming processes are that:

* The work piece is a sheet or a part fabricated from a sheet;

* The deformation usually causes significant changes in shape, but not in cross section of the sheet;

* In some cases, the magnitude of permanent plastic and

recoverable elastic deformations are comparable; therefore, elastic recovery or springback may be significant. Harder metals cause more degrees of springback.

The variables of the drawing operation are shown in the figure 16.

C. <u>Hudson Tool and Die Company</u>

Hudson Tool and Die Company specializes in difficult, deep drawn stampings and is in a competitive business. Since it has no proprietary products, the company must bid for and win its workload every year. It is known nationwide as a leader in deep drawn parts.

Most of the parts manufactured at the Hudson Tool and Die Company are by blanking, cup drawing, deep drawing, ironing, bending, and trimming operations. Drawing consists mainly of metal flow rather than metal movement. There are basically four types of drawing operations: cupping, box drawing, shallow panel drawing, and deep panel drawing (see figure 16). The drawing of cups is the simplest drawing operation and more easily illustrates the theory of drawing (see figure 17). The blank required for cupping is round. Drawing consists mainly of metal flow rather than metal movement. Deep drawing is very important in sheet-metal working. It is defined as the combined tensile and compressive deformation of a sheet or foil, or blank to form a hollow body, or of a hollow body to form a hollow body of a smaller size, without intentional change of sheet thickness. The metal flows through the opening provided by the clearance between the punch and the die and the die and blank holder.

There are three sub-groups of all the deep drawing operations. [10]

1. Deep drawing using dies
2. Deep drawing using a working medium
3. Deep drawing by energy activation

The deep drawing of a blank to form a can, or cup, is referred to as first draw, while the subsequent deformation to create a hollow body of smaller diameter is termed redraw. This process is used to produce cylindrical or prismatic cups with or without a flange on the open end. The variables of drawing operation are shown in figure 18.

The two major drawing defects are wrinkles and tears. To prevent wrinkles from occurring at the edge of the blank, a blank holder is added around the punch. The blank holder pressure must be low enough to allow the metal to move or flow underneath it. The blank holding pressure causes a high force due to friction. Therefore, a lubricant must be applied to reduce the friction. The metal is often scratched or scored when moving under the blankholder, excess metal is provided in the blank. This excess scored metal is cut away by the trimming operation. Surface finish of die components and of sheet metal are important factors to determine the friction force.

Various forces which occur during drawing are: [10]

1. Bending at the radii;

2. Friction between

   a.Blankholder and sheet metal;

   b.Die steel and sheet metal;

   c.Punch steel and sheet metal;

3. Compression at the flange area or extremity of the cup.

The analysis of force is as follows:

Friction+Compression+Bending = Punch Force

If the punch force exceeds the ultimate tensile strength of the metal, the wall will break. Other defects of drawing are Orange Peel, Alligator Skin, and Earing. When metal is severely stretched, it loses the shiny surface finish and become dull. It is said to have an orange peel appearance. If hardness or strength of the sheet metal is non-uniform, the surface may have a patchwork of reduced areas resembling alligator skin. To prevent this defect, the sheet metal is passed through a roller leveler. When sheet metal is rolled, a fibre structure is formed in the direction of rolling. Strength is lower across the direction of rolling and it is more along the direction of rolling. Due to this variation in strength, the top edge of the cup is wavy. The wavy condition is called "earing". This wavy edge is trimmed off and must be allowed for when determining the blank diameter.

The process of bending is widely used for forming flat sheets into linear sections, such as angles, channels and hats (see figure 19).

The process of ironing is employed in the production of a variety of cans and tubes. It is usually performed as a redraw operation to obtain uniform wall thickness. During ironing, the diameter and thickness are reduced considerably. Ironing is well adapted to making cylinders with a length that is too long in relation to the diameter for drawing from sheet metal.

Trimming is usually required after the drawing operation. During drawing, the edges of the flanges, or the top edges of the cup, tend to become scalloped in appearance. It is caused by variations in metal strength as a result of the grain direction produced by rolling. Pinch trimming is commonly used on light materials, where no flange is required in the finished parts. With shallow drawn parts, drawing and pinch trimming can be accomplished in one operation. Pinch trimming is fast and inexpensive, but has the disadvantage of leaving a sharp outer edge. Horizontal trimming is accomplished by horizontal motion of the press ram. Although this process is more expensive, it has the advantage of forming a sharp burr on the inside edge of the cup rim (see figure 20).

CHAPTER VI EFFECTIVE AND ENDURING SQC SYSTEM

A. Challenges to implementing SQC

It is no secret that management throughout America is under heavy pressure to deliver high-quality products at reduced costs. Toward this end, SPC is being increasingly used, and significantly considered instrumental in institutionally a true quality culture.

Implementation of ongoing, effective SPC improvements requires a thoroughly conceived methodology. Further, to be successful, the approach must be practical and reproducible; it must be implementable in a real world organization comprising of various groups with competing problems and priorities.

The challenges to implementing SPC introduce themselves at the very start of the process. Figure 21 shows the various phases for implementing SPC. New procedures and productivity enhancement programs have become everyday occurrences. SPC is all too often mistakenly viewed as merely the mere presence of statistical tools, usually control charts. The problem is that production processes have become quite complex; hundreds of measurements are routinely taken, recorded and charted daily. It is not unusual to hear of a process with large amounts of unnecessary scrap and rework resulting from problems clearly shown on appropriately implemented but unused control charts. This leads to the third challenge of SPC introduction: the lack of clear instructions as to what actions are required when out-of control conditions are identified. People will not react without having clear procedures that specify how to react. A fourth challenge might be called people problems. Introduction of new technology always meets resistance, which must be overcome through training and introduction. The key to success in motivating is the involvement of management in the training process.

Statistical process control at Hudson Tool and Die Company, Newark, NJ, began evolving about ten years ago. SPC was successful in achieving cost reductions and improved efficiency. Quality Control Manager Mr.Anthony Pastena was assigned to implement SPC and to train the first line supervisors. The workers were expected to understand the need for process control and to be able to recognize and react to out-of-control conditions.

B. Basic procedure

Key components of establishing an effective SPC process lies in resolving gaging problems, machine capabilities, and material variations. Defining the process is really a brainstorming event during which employees, supervisors, and managers come together to gain an understanding of the operation. Bringing people together to break down and discuss the important parts of an operation produces a sharing of perceptions and insights. The working definition of a process must include its beginning and end. Taken to the extreme, it can be said that a process starts at the suppliers' plants and ends with the customers' receipt of products. A process involves the operation that is under direct control of the machine operators. The sheet metal parts manufactured at Hudson Tool and Die Company involves various forming operations on power presses. The company has high tech pneumatic, hydraulic, and mechanical power presses with a wide range of speed and force capacity. Manufacturing engineers determine the number of operations and the sequence of the operations. Usually the parts requires four to six operations to finish. Punch and die design requires careful analysis and are made on a wire electro discharge machine (EDM).

Once the process is defined, management determines the important characteristics. In the forming operations important characteristics to study are metal thickness, radius of the curved metal, depth of drawing operation, and burr formation. It is important to assure that measurement is satisfactory. Gages should be accurately calibrated and the gaging procedure should be defined. Checking the ability to make measurements is an important foundation for all subsequent SPC activities. The capability study is carried out to discover variation under a given set of conditions. A stable process and a capability is determined that can demonstrate a safety margin better than the specification requirements.

During a regular production run, process performance studies are conducted to determine the variation present, with all sources of variation in place. It is really an extension of capability study. The differences are in the time frames and the allowed exposures to the sources of variation. At Hudson Tool and Die Company, this step was used as a vehicle for teaching the operators the use of control charts. As charts are used at the machine during the process performance studies, they are reviewed by SPC coordinators with the operators on the factory floor. The charts indicate to operators when to correct the process. The result is fewer corrections and a more consistent product. The important factor of this step is to prove that the job can be accomplished as expected.

The assessment of the control of the process can be made by only through the use of statistics. An integrated software STORM was used for the analysis.

C. Integrated software STORM

Integrated software STORM was used for obtaining control charts and for the analysis. The variables control charts which STORM include are:

1. Average chart
2. Range chart
3. Fraction nonconforming chart
4. Standard deviation chart

STORM is provided with many criteria to determine when a process is operating in a nonrandom fashion. For each case, data are entered in the data base in the same order they were produced.

The criteria may be broadly classified as simple criteria and statistical criteria. The simple criteria supported by STORM include:

1. A run of seven or more points above or below the center line;
2. A run of seven of more points up or down;
3. A run of two or more points outside two standard deviation limits;
4. A run of three or more points outside one standard deviation line.

The statistical criteria supported by STORM include:

1. A point outside control limit;
2. The number of runs above or below the center line;
3. The length of the longest run above or below the center line;
4. The number of runs up or down;
5. The length of the longest run up or down.

These criteria have been coded with values from zero to eight for listing on STORM reports.

D. Selected Examples

Most of the customers of Hudson Tool and Die Company ask for the SPC charts for the parts manufactured. Each product has a particular characteristic of concern which must be checked and maintained. The various characteristics of concern for sheet metal parts include thickness of the deep drawn part, depth of the drawn part, radius of the bend and the formation of the burrs.

The first part studied was littlite chassis. It is shown in figure 22. The main characteristics under study were the length, the height, and the width of the part. The sequence of the operations is blanking, drawing, and piercing. All the dimensions were checked at the same time. Data was gathered for these characteristics. Three criteria have been used to show the out-of-control condition. These three are, points outside control limits, a run of seven or more above or below the center line, and a run of seven or more up or down. These criteria have been coded with the values, 0, 3, and 4 successively. A run of seven or more points above or below the center line is the famous engineering rule of seven. These criteria are used when the samples are submitted in their exact order of production.

A random sample of three parts was taken every thirty minutes until twenty samples were collected. After entering the title, the number of samples was entered. This number determines the number of rows in the data set. A value of three was entered for the number of variables. Zero was entered for the number of attributes because there were no attributes to observe. The next entry represents whether the data is raw or summarized. Raw data means the original measurements are entered before any statistical processing has taken place. Summarized data means that the data have already have been summarized into statistics. The sample mean, range and standard deviation for each variable should be entered for the summarized data. All the problems have been analyzed using row data. STORM performs the statistical calculations.

Average and range charts were obtained for the littlite chassis. Figure 23 and 24 shows the decision charts for working with averages and ranges. It describes the sequence of steps for the analysis of the average and the range charts. Figures 25 to figure 30 show average and range charts of length, height, and width of the part. As raw data were entered, STORM performs necessary calculations for the charts. The dotted lines on either side of the center line are the two standard deviation limits. The extreme vertical lines are control chart limits. Codes of out-of-control criteria appear at the head of the rightmost column. Because of the inherent variation, points move up and down on the charts. Checks on the charts are made promptly so that the remedy is immediately effective.

When the average is outside the control limits, it indicates that the process must be adjusted. It can be seen from the figure that the average is outside the limits and the process should be adjusted. Usually an assignable cause points to a problem that can be handled at the floor level, such as the need to adjust the tool setting. The average chart of length is out of control at the beginning of the production. The process is out-of-control in the beginning because the die was not properly set up. Once the die was adjusted, subsequent readings were within the control limits. Causes which can affect the control charts are marked on the charts for the permanent record. The discovered causes can often be helpful in studying other products.

SPC was performed for the manufacture of slotted cans. Figure 31 shows a slotted can. The deep drawn part has two slots which are 0.13 inch above the bottom of the part. Thickness of the drawn part was one of the critical characteristics to be studied. This part is made on four machines. Two machines performs drawing and redrawing operation and the other two machines performs piercing operations for slot and hole of the can. The part was checked for material thickness, length of the slot, slot height, and the hole diameter. The processes are stable and points lie inside the control limit. Figure 32 to figure 39 show average and range charts for the various characteristics.

A nonmeasurable characteristic was under study for the part shown in figure 40. The part was too long and it was drawn twice to obtain the required depth. In the past it was observed that scratches appeared on the outer surface of the drawn part. A sample of five parts was examined every thirty minutes for visible defects, mainly scratches on the outer surface of the drawn part. These scratches could not be removed and the part was rejected. The distribution had been divided into two parts, defective and non-defective by visual inspection. Thus the **p**-chart is used to show the general level of a process in terms of percent defective to indicate overall trend of the process.

Figure 41 shows the **p**-chart for cover. The die and the die bed should be clean in order to avoid any dust particles or chips that could be pushed in when the part is being deep drawn.

The radius of the vertex of the bending punch is important in bending operations. If it is too small, the metal in the bending zone is subjected to high stresses, chiefly tensile, and may fail in service. In making a bend, fibers on the inner radius are compressed and shortened, while those on the outer side are stretched. As a result, there is a small net stretching of the blank when it is bent. There are no set rules for fixing the minimum bending radii, because these depend on several variable factors, especially the kind, gage, and temper of the stock. Definitive values can be determined only by practical trials under actual conditions.

SPC was performed for the manufacture of U-bends. Figure 42 shows a U-bend. The main characteristics under study were the radius of bend and the height of the legs. An extra pilot hole is provided to ensure accurate location of the bend. This part is made on two machines. First machine performs blanking and piercing operation and the other machine performs bending operation. A sample of three parts was examined every thirty minutes until twenty five samples were collected. The material of U-bend was brass and the stock thickness was 0.1 inch. Figures 43 to 46 show average and range charts of radius of bend and height of the part. The average chart of the bend radius is out-of-control in the beginning because the punch radius was to be adjusted. After the punch radius was changed, subsequent readings were within the control limits.

E. Discussion and Conclusions

Recent developments have made quality much more a science than an art of form. The body of knowledge related to quality is now well defined, and it is becoming increasingly sophisticated.

Quality control is a body of specialized knowledge that encompasses disciplines as diverse as mathematics and management, psychology and engineering, the law and human relations. The primary purpose of quality control department is to make sure that there will be direct and constant co-operation between operating and engineering in all problems having to do with quality control, and also that the statistical methods are used properly and consistently.

Many companies have proven that it is possible to improve quality while decreasing costs. Such a program is achieved by discarding the old additional inspection assumption and replacing it with a statistical process control system that "produces all things right the first time."

Statistical application in industry actually involves three separate functions. These functions are data analysis, statistical sampling, and process control. Trained statisticians are needed for the data analysis and statistical sampling functions, but only statistical logic, without the need of statistical terms, is needed for process control. Unfortunately, there are not many successful process control programs in the United States. It is felt that this lack of success is due directly to the training that has been performed for most programs. Experience shows that when the proposed program is presented using statistical logic but not statistical terms, instead of being turned off, production workers are actually enthusiastic because they can see that statistical process control is a most logical operation mode.

It is possible to go as deeply as one wish into the interpretation of control charts. However, the most important meanings are very simple, and anyone can learn to make these interpretations after seeing only a few charts.

Process control chart are of two principal kinds: those intended to control the quality of work going to the next operation, and those intended to minimize losses or "dropouts" at the original operation.

The number of charts tends to be small where only the operator's technique is involved, and tends to be larger where the variables include both operators and machines.

CHAPTER VII EXPERT SYSTEM BASED STATISTICAL PROCESS CONTROL

A. Introduction

In recent years, the number of applications of expert systems has steadily grown. The emergence of expert systems provides new insight to specialists in manufacturing systems as a means of solving problems in their domain. Operations research and management science disciplines have provided a variety of problem-solving algorithms for decades in this context. Optimization techniques developed by operations researchers were aimed at using computers to deal effectively with real world problems. Expert systems and operations research share a common goal of developing practical methods for solving intractable problems with different emphasis. Decision aid in the form of a consultation system is the end product of both approaches.

Quality control is a major component of any methods improvement program with the objective of minimizing losses due to rejection, scrap, and reworked production. Statistical process control contributes to this objective by helping the company to understand its operations as a set of processes.

A process must be a value-added activity with inputs and measurable outputs. In general, if the outputs cannot be measured, they cannot be managed. Hence, available process measurements must be presented in a way to communicate the state of the process to management and the personnel involved in the process.

B. Zero defect production with expert system based SPC

Process specific expert system based SPC can be used in production as a reliable partner for the machine operator to control the process better. Selection of a structure for representing knowledge is one of the important issues of expert system design. The knowledge from the particular process-multispindle machining, grinding, turning, or milling, is embedded in a rule based expert system.

The program makes direct recommendations regarding minimum sample size and the necessity to compensate for a drift in the process. Incorporating mathematical expertise, expert-system software can automatically determine rational subgroup size as samples are measured initially. Deciding the sample size is important because a process cannot really be controlled with minimum required inspection activity. Responding to process variation, the software estimates the optimal sample size after each data entry. If a machining process drifts away from the nominal, the program tells the operator to increase the frequency of inspection and/or the sample size to maintain control. The machine operator is always advised to take specific corrective actions when required and directly interacts with the message from the computer. Statistical activities, such as setting and modifying control limits for averages, ranges and deviation, capability studies, and evaluation of frequency distribution, are provided by the expert system. In process capability studies are generated by the expert system software. The software provides a very good picture of the centering and the range of the process and helps to maintain the process well centered between the control limits. A centered process with a narrow spread is a process approaching zero defects.

There are many misconceptions about the use of basic types of control charts. Control charts are a very effective way of showing the capability and state of control of a process. Some control charts can provide information on the process mean and variability, while others provide information on the average number of defective items produced by the process. Each control chart type is designed to provide some information about the process. Deciding which control chart type is appropriate for a specific process can be a difficult task requiring expertise that can be represented through out an expert system.

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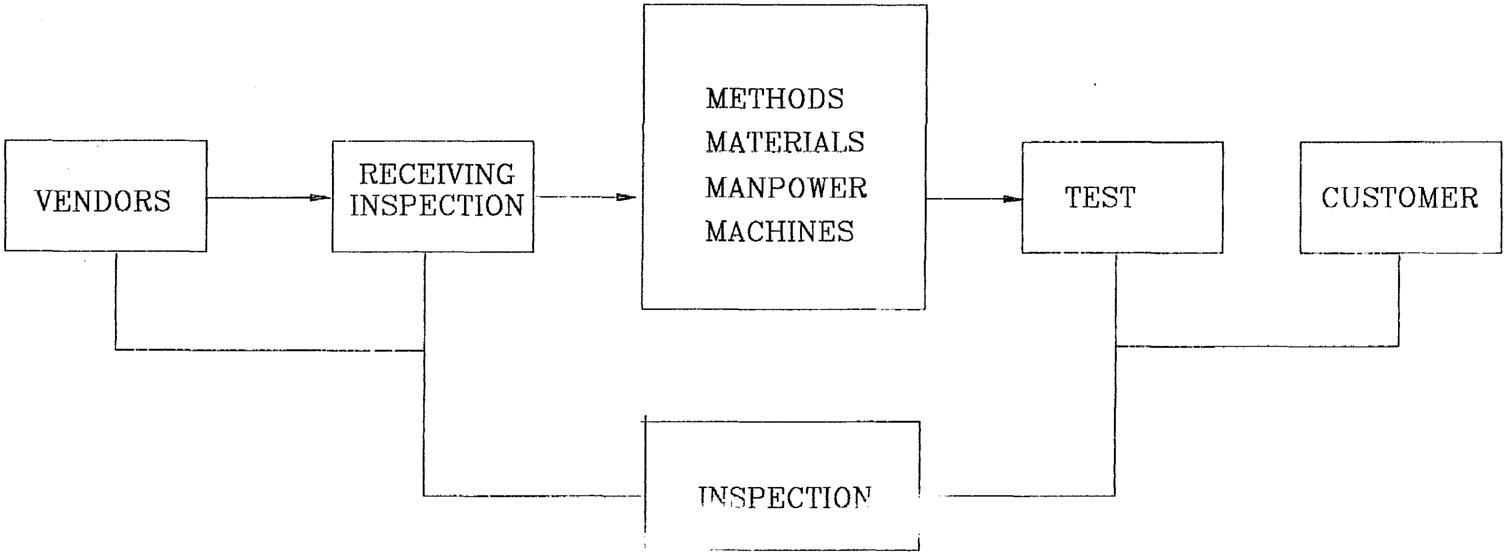
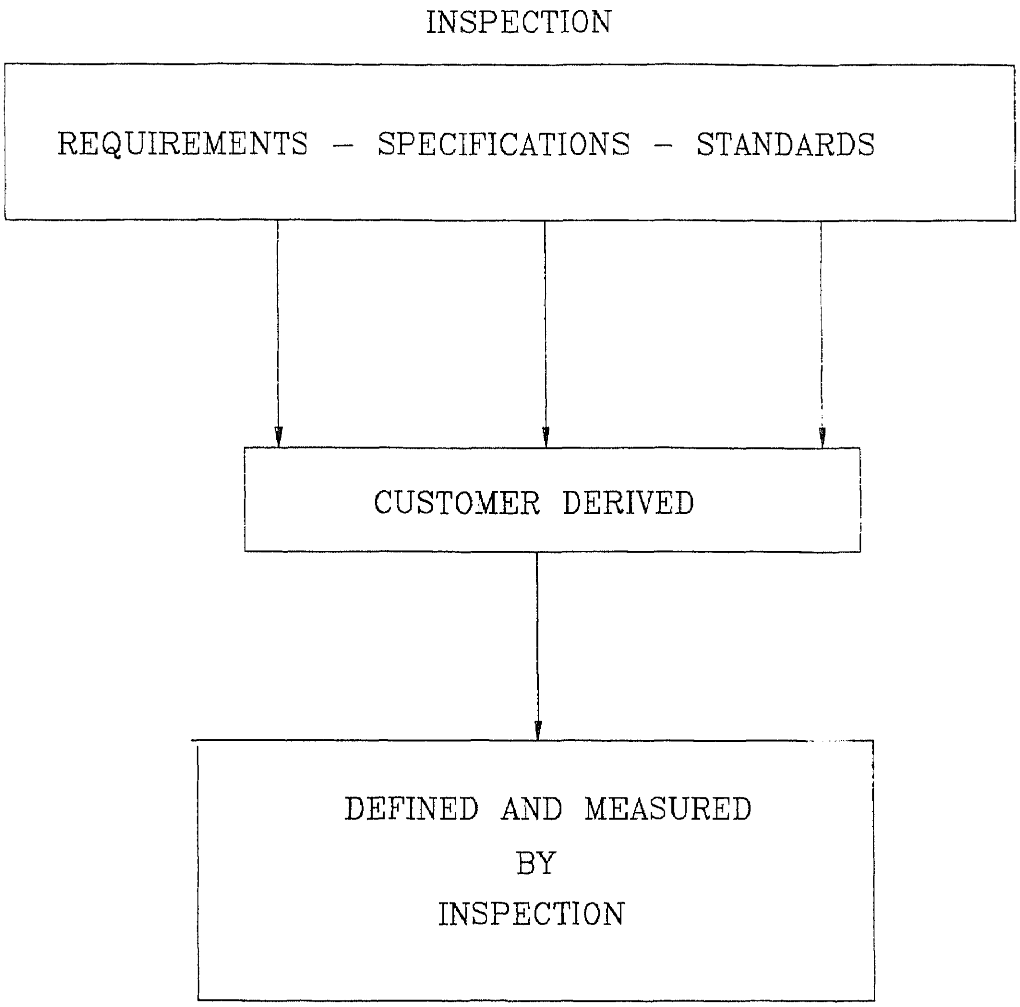


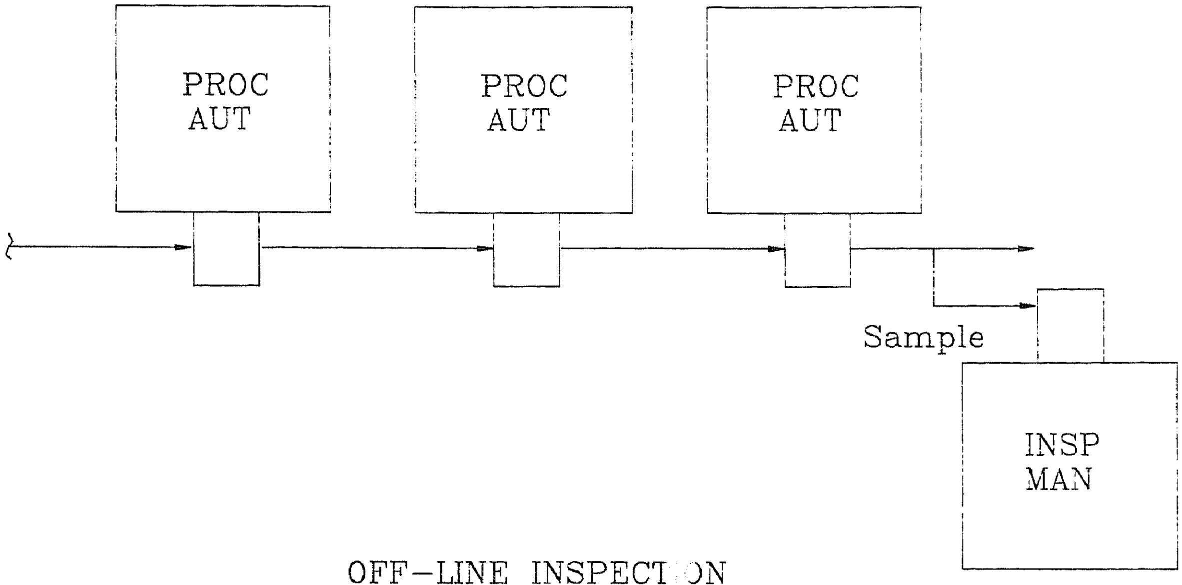
<u>INSPECTION PROCESS</u>

Figure 1



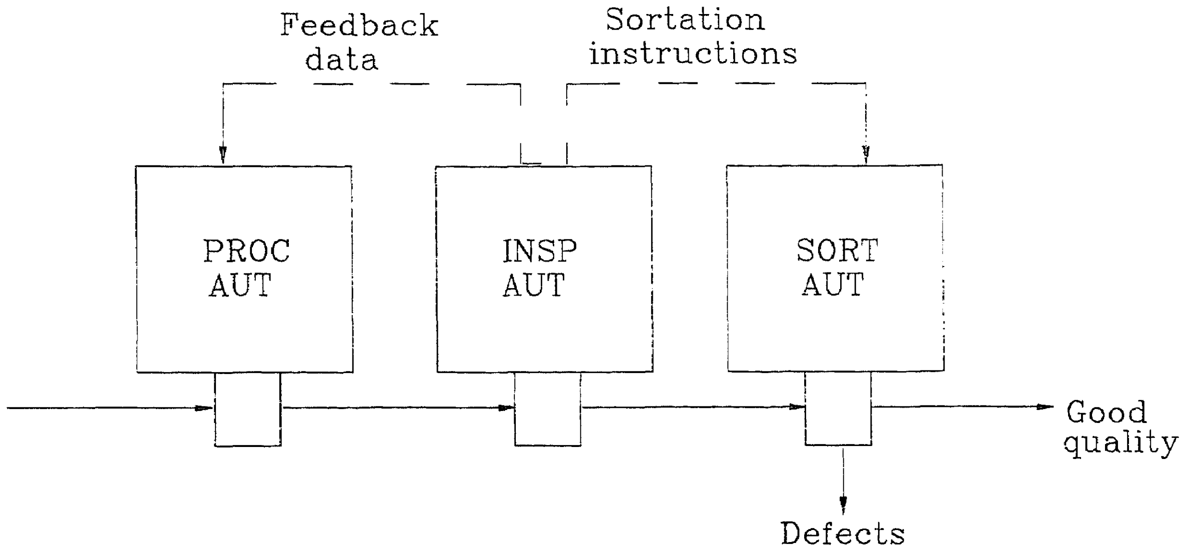
THE NEED AND FUNCTION OF INSPECTION IN INDUSTRY

Figure 2

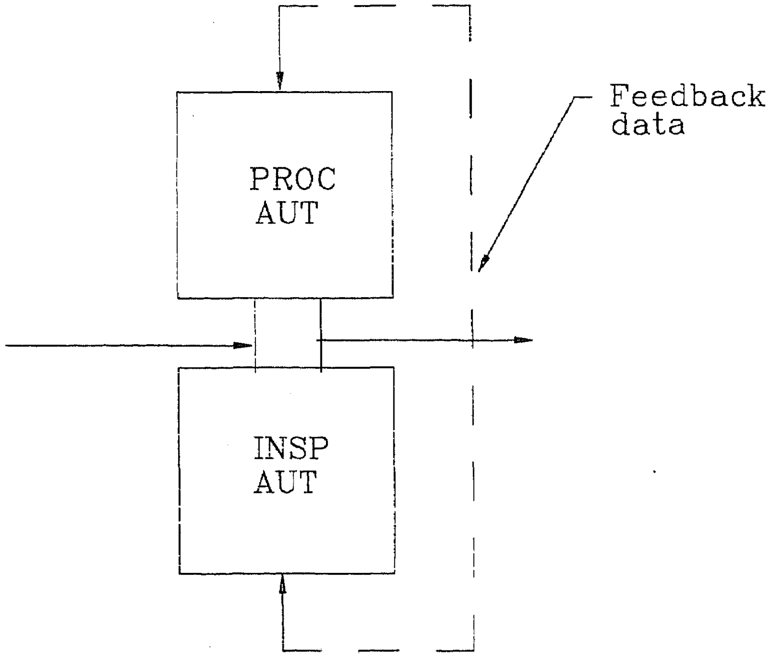


OFF-LINE INSPECTION

Figure 3



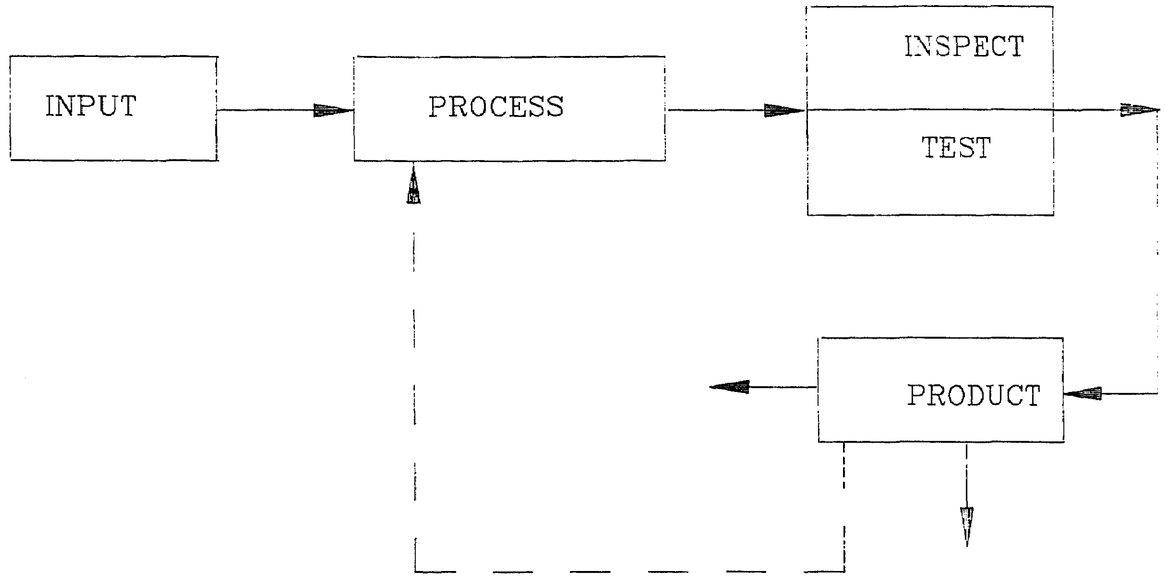
ON-LINE POST PROCESS INSPECTION



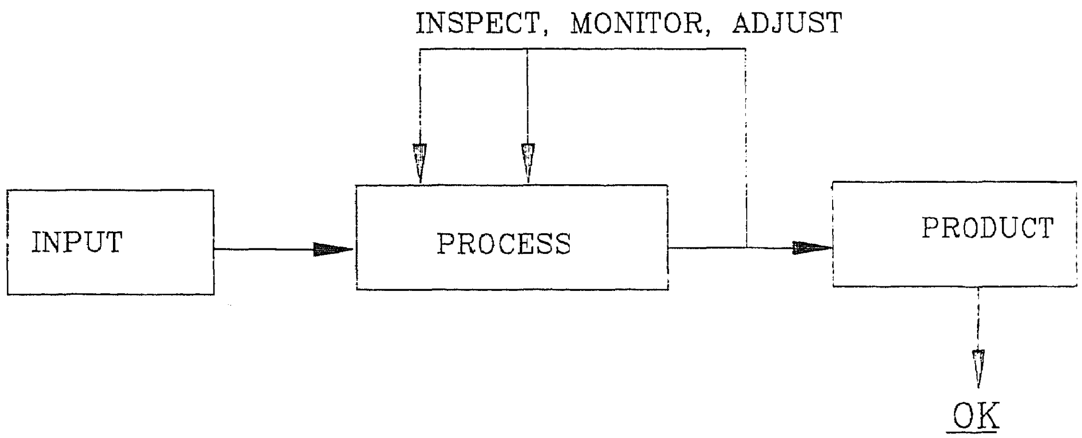
ON-LINE/IN-PROCESS INSPECTION

<u>ON-LINE INSPECTION</u>

Figure 4

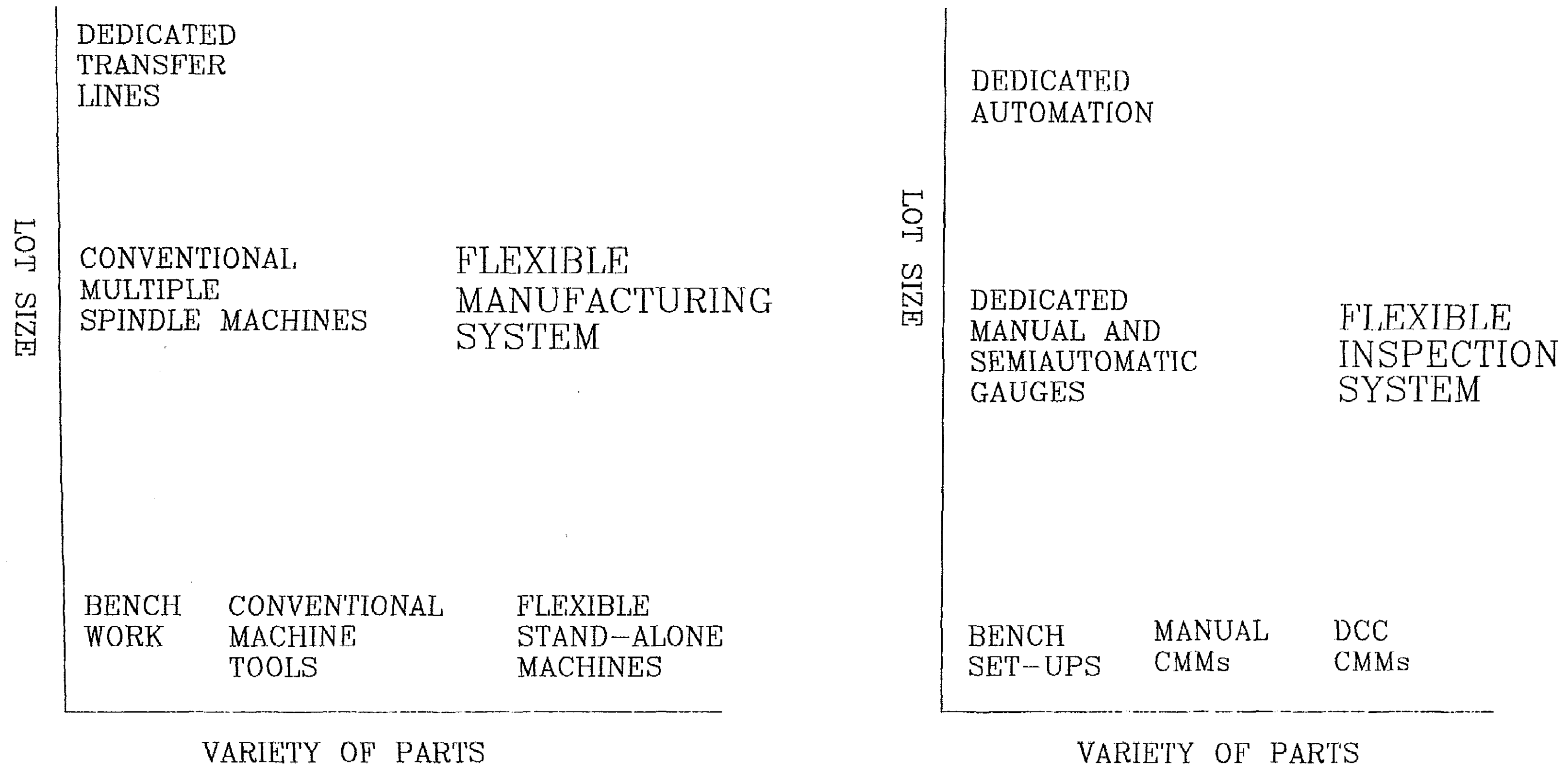


DEFECT DETECTION



DEFECT PREVENTION

Figure 5



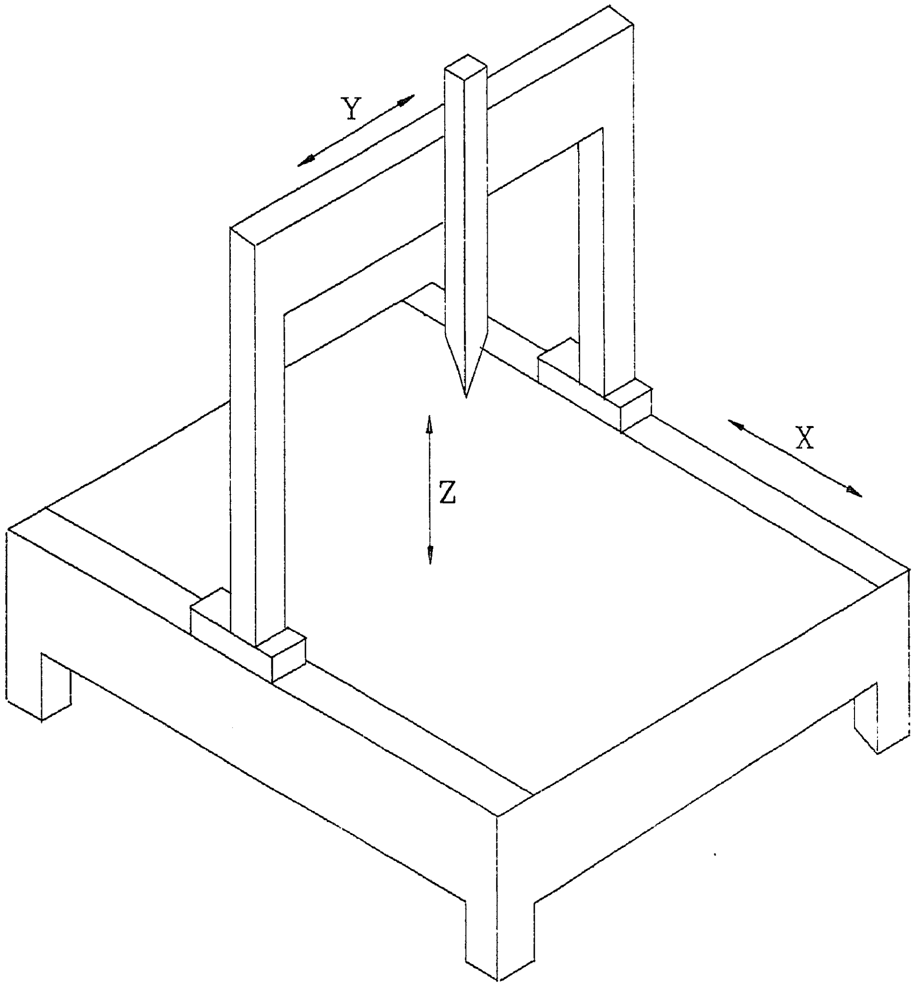
VOLUME/VARIETY OPTIONS FOR PARTS

VOLUME/VARIETY OPTIONS FOR INSPECTION EQUIPMENTS

* FLEXIBLE MANUFACTURING SYSTEMS ARE CURRENTLY BEING USED TO MAKE A MODERATE NUMBER OF DIFFERENT PARTS IN MODERATE LOT SIZES.

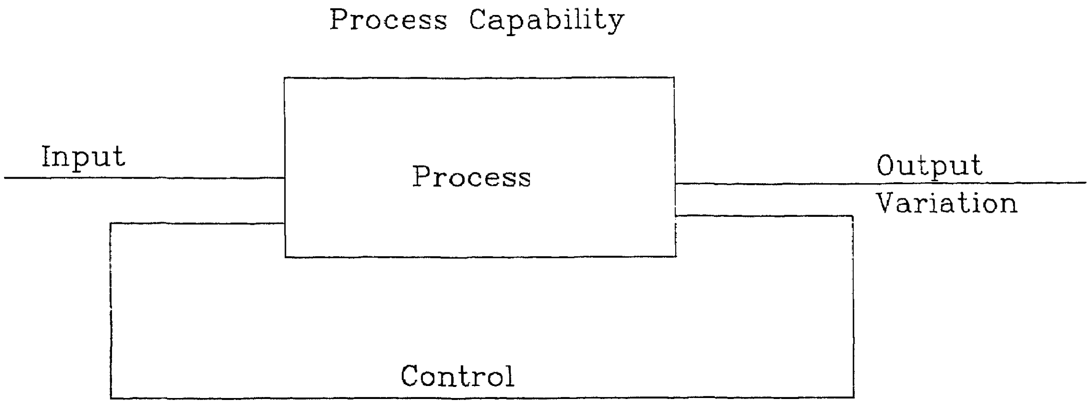
* FLEXIBLE INSPECTION SYSTEMS SERVE THE FLEXIBLE MANUFACTURING SYSTEMS

Figure 6

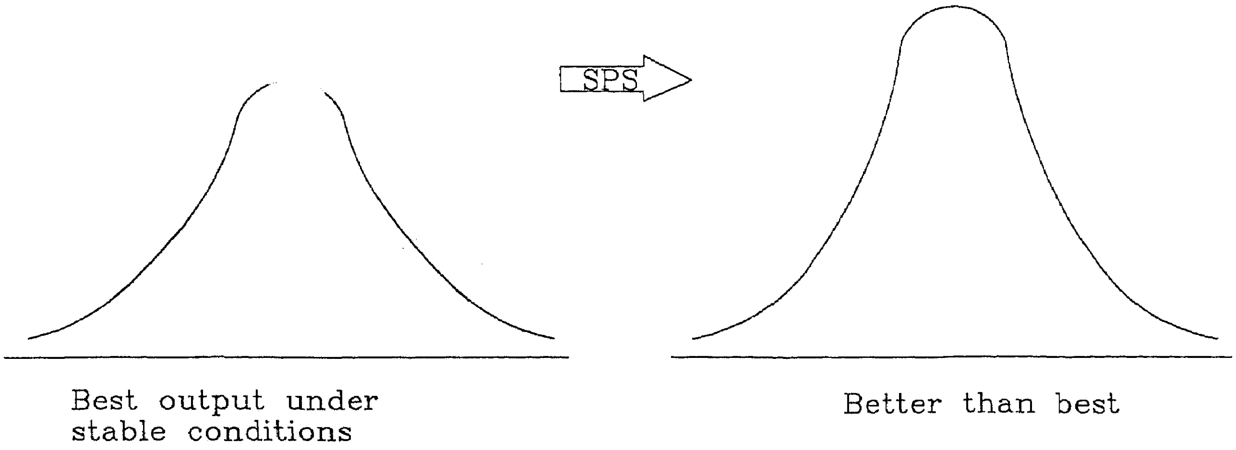


BRIDGE CONSTRUCTION OF COORDINATE MEASURING MACHINE

Figure 7

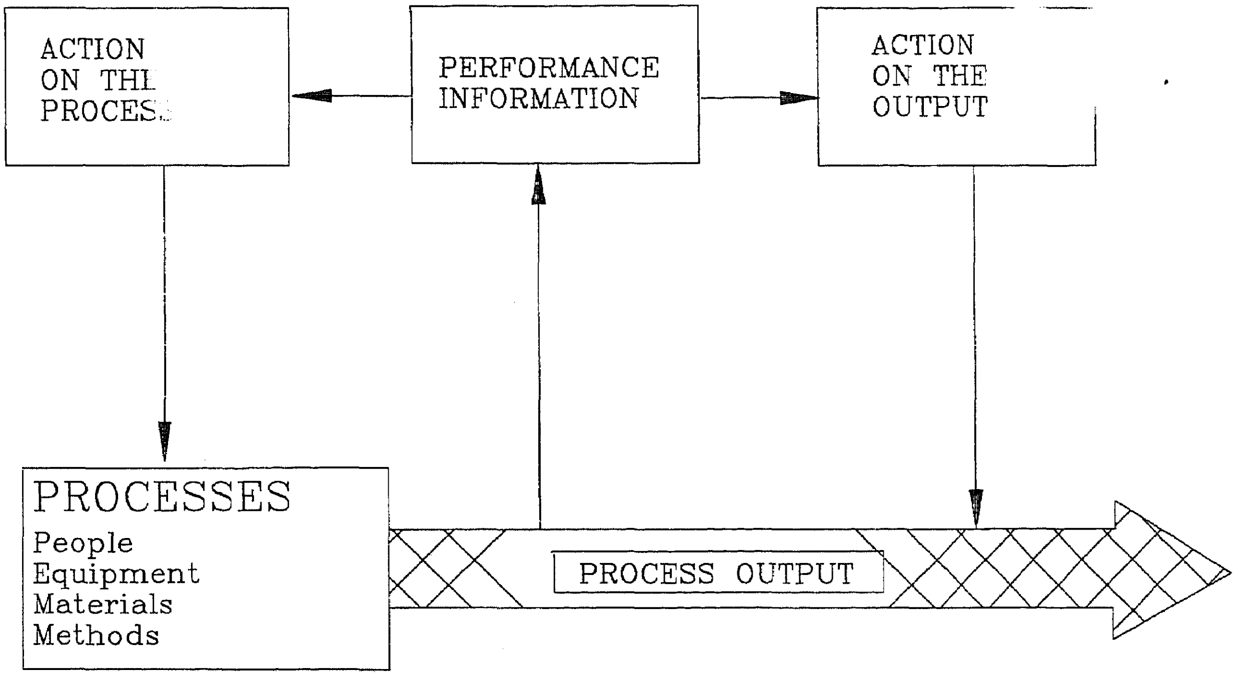


PROCESS ELEMENTS



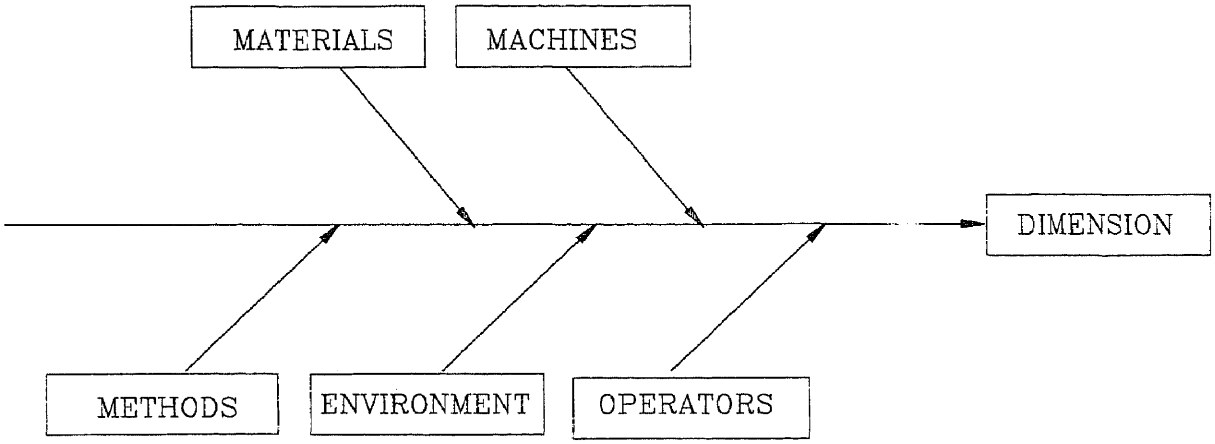
REDUCING STATISTICAL VARIATIONS

Figure 8



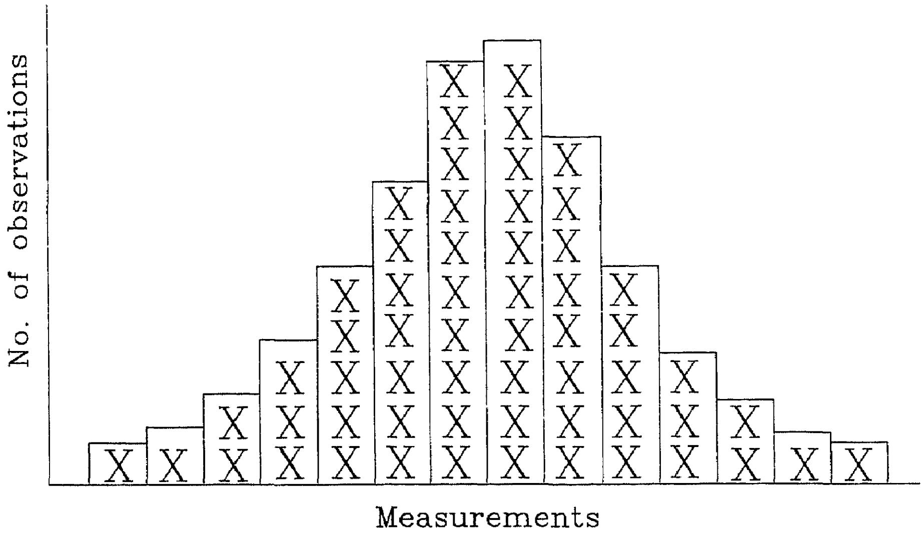
A PROCESS CONTROL SYSTEM

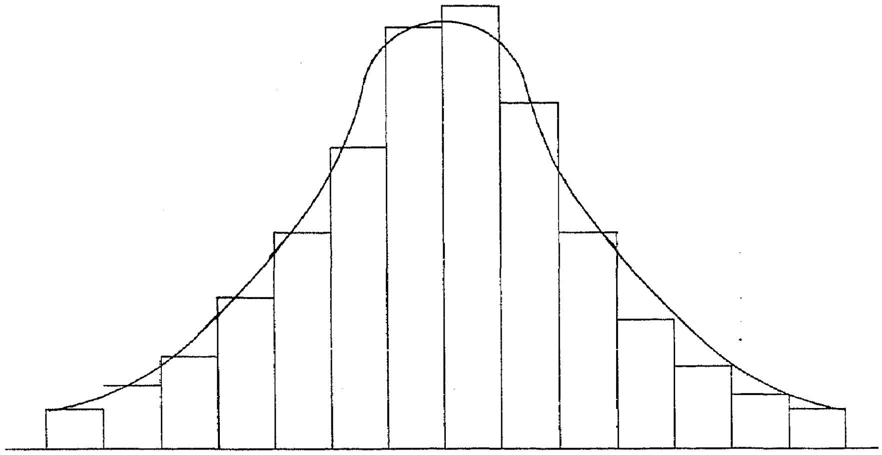
Figure 9



<u>FISHBONE DIAGRAM</u>

Figure 10

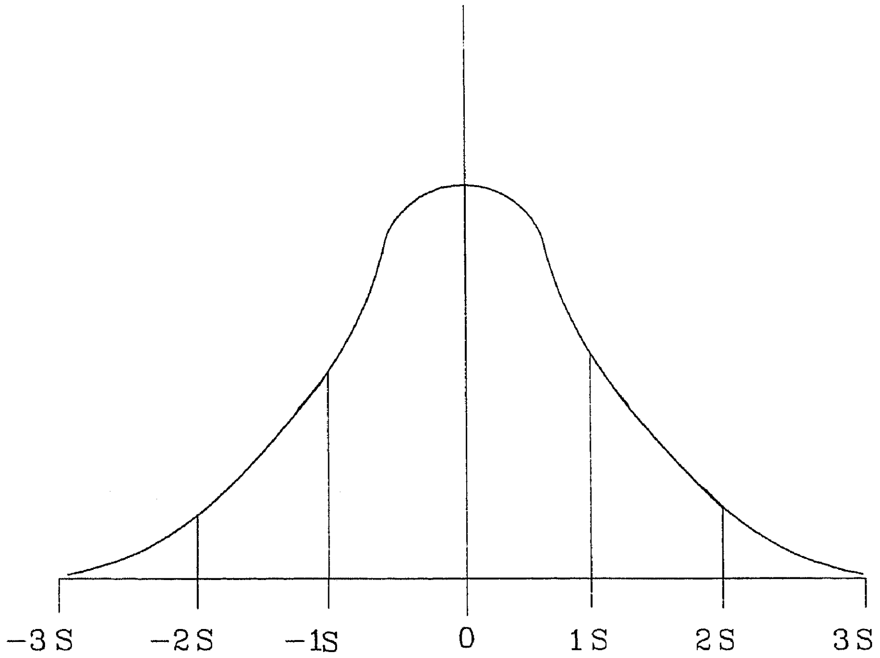




Normal curve compared with the histogram

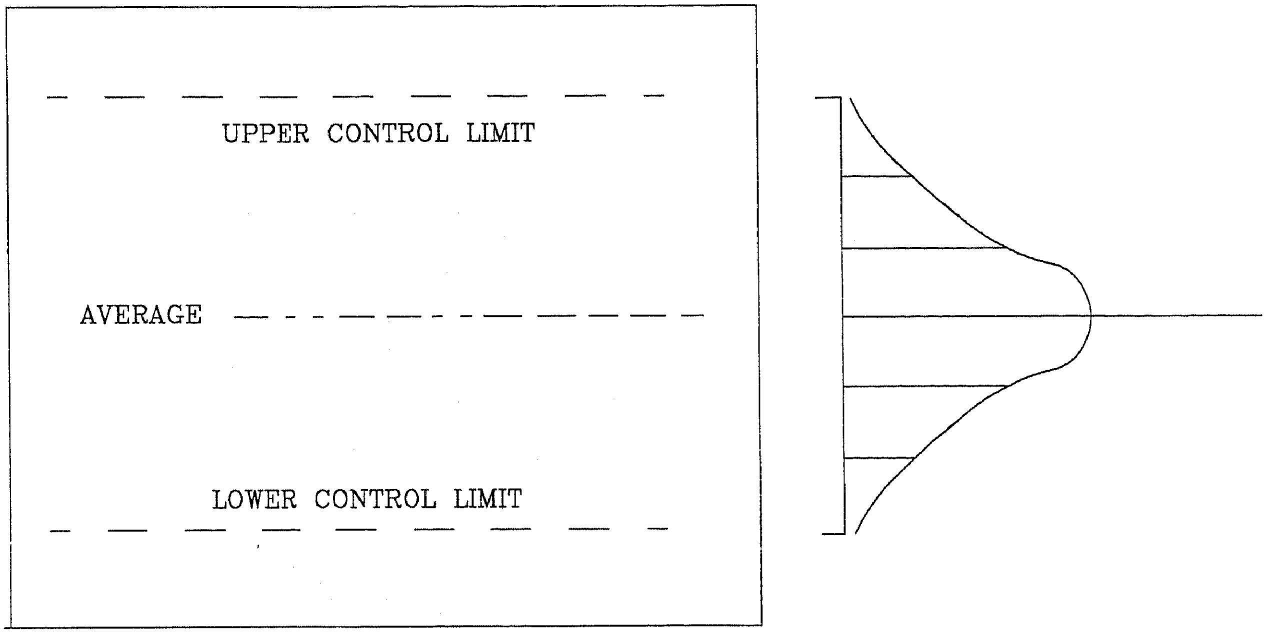
HISTOGRAM

Figure 11



NORMAL DISTRIBUTION

Figure 12



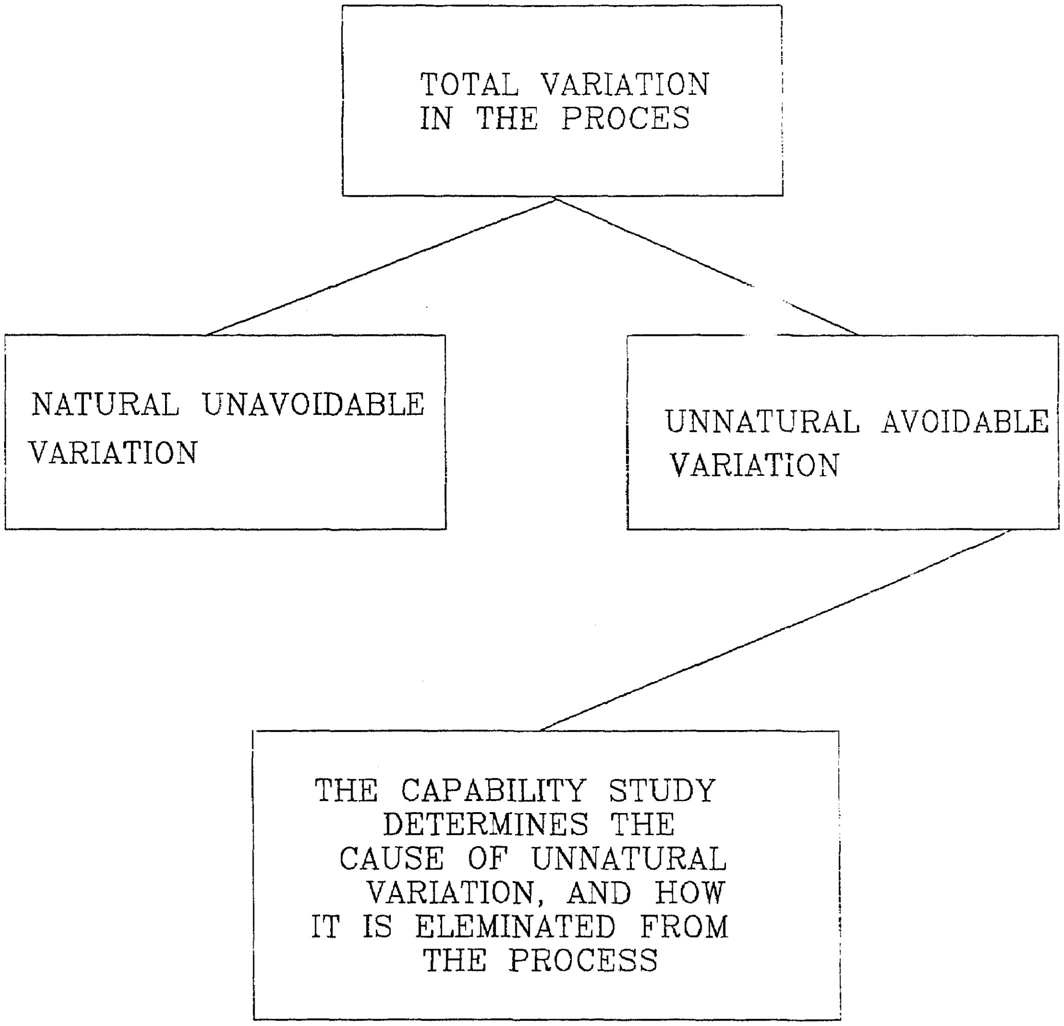
How a control chart is related to the normal distribution

Figure 13

CHARACTERISTIC	PROCESS CAPABILITY STUDY	PROCESS CONTROL CHART
PURPOSE	To obtain information	To obtain a predetermined distribution.
SAMPLES	Relatively few.	A running series.
ANALYSIS	Very careful analysis and interpretation.	Only the more obvious changes are observed.
ACTION	Any change may be important.	Only unwanted changes are acted upon.
INFORMATION	Distribution shape is studied as well as average and spread.	Attention focused mainly on average and spread (or percent defective).
RELATION TO SPECIFICATION	Relation to specification is carefully checked. The study may lead to a change in either the process or the specification.	Proper relationship to specification is allowed for when the control chart is set up.

Difference between a process capability study and a process control chart.

Figure 14



TRUE PROCESS CAPABILITY IS ACHIEVED WHEN THE UNNECESSARY VARIATION IS ELIMINATED.

<u>PROCESS CAPABILITY STUDY</u>

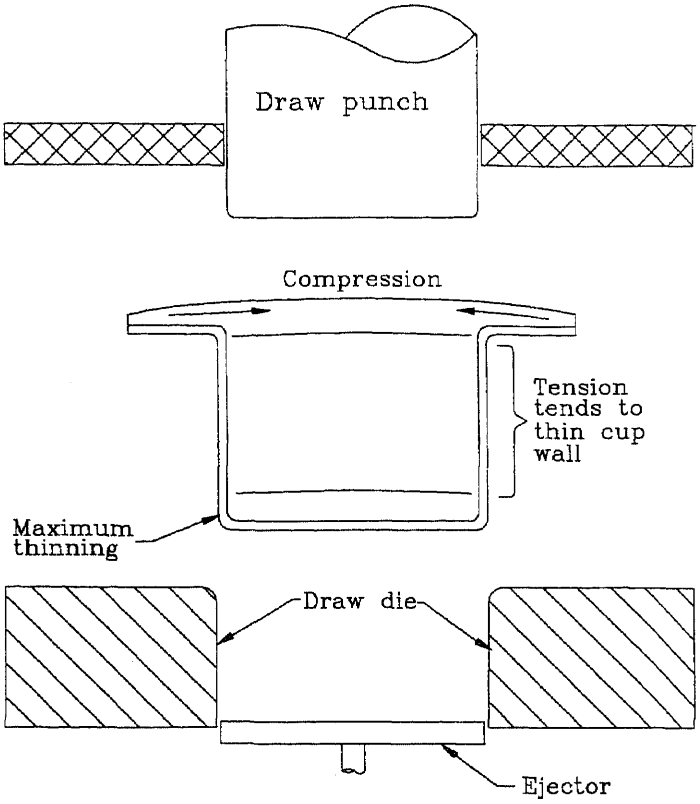
Figure 15

SHEET METAL DRAWING OPERATIONS

- **CUPPING**
  DRAWING OF PARTS HAVING A CIRCULAR OR CYLINDRICAL SHAPE.
- **BOX DRAWING**
  THE DRAWING OF SQUARE OR RECTANGULAR SHAPE.
- **SHALLOW PANEL DRAWING**
  DRAWING OF IRREGULAR SHAPED PARTS WITH LOW DEPTH.
- **DEEP PANEL DRAWING**
  DRAWING OF IRREGULAR SHAPE PARTS WITH GREAT DEPTH.

* EACH OPERATION CAN HAVE REDRAWING OR REVERSE DRAWING OPERATIONS. IN REDRAWING, A DRAWN PART IS REDRAWN TO INCREASE THE DEPTH AS DESIRED. IN THE REVERSE DRAWING OPERATION, THE DRAWN PART IS PLACED UPSIDE DOWN AND DRAWN FURTHER.

Figure 16



Drawing Operation

Figure 17

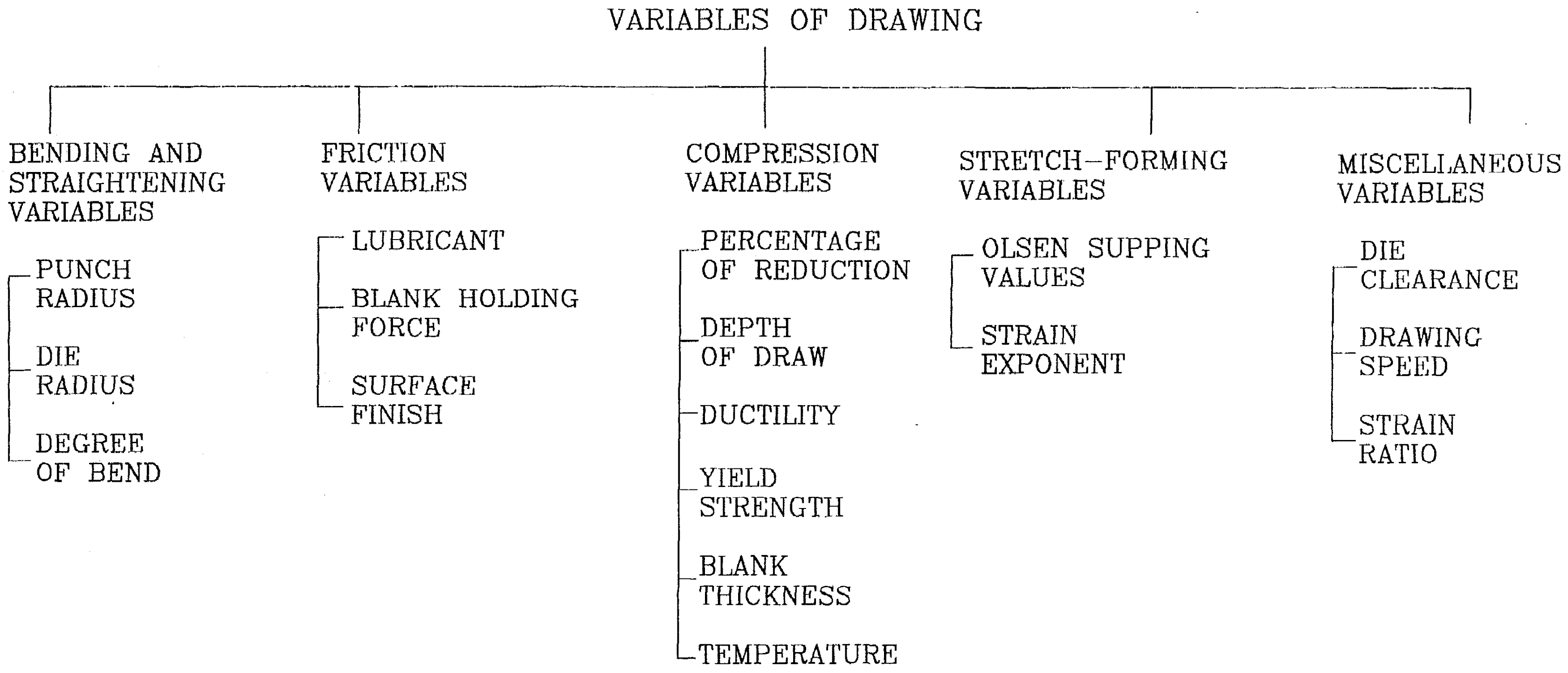
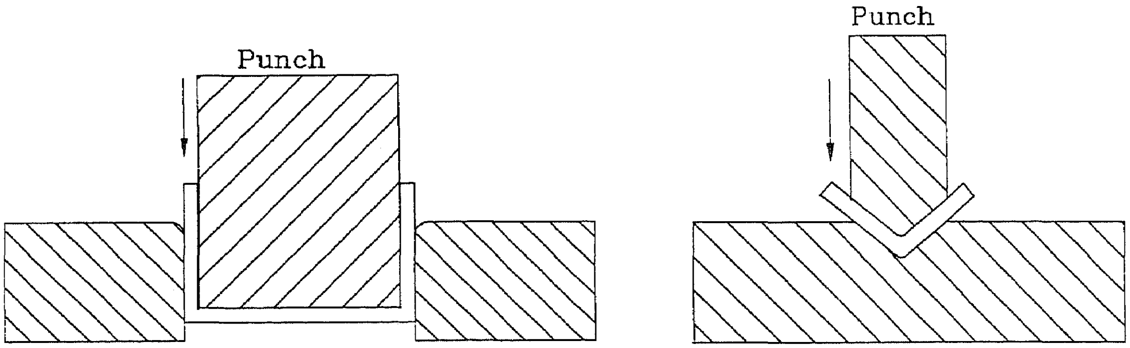
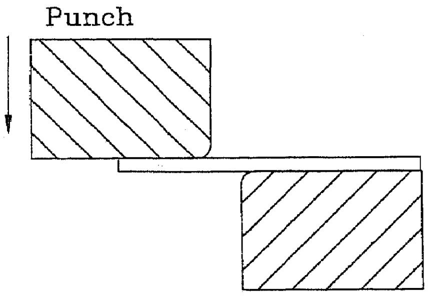

VARIABLES OF DRAWING
BENDING AND STRAIGHTENING VARIABLES
PUNCH RADIUS
DIE RADIUS
DEGREE OF BEND
FRICTION VARIABLES
LUBRICANT
BLANK HOLDING FORCE
SURFACE FINISH
COMPRESSION VARIABLES
PERCENTAGE OF REDUCTION
DEPTH OF DRAW
DUCTILITY
YIELD STRENGTH
BLANK THICKNESS
TEMPERATURE
STRETCH-FORMING VARIABLES
OLSEN SUPPING VALUES
STRAIN EXPONENT
MISCELLANEOUS VARIABLES
DIE CLEARANCE
DRAWING SPEED
STRAIN RATIO

Figure 18



U bending dies

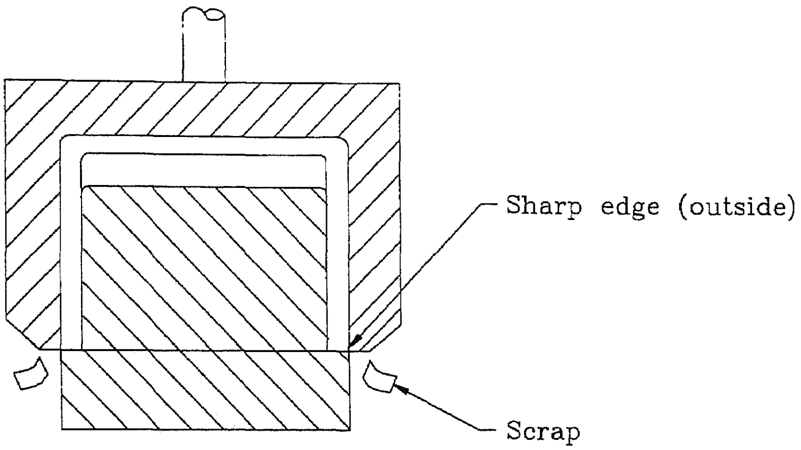
V bending dies



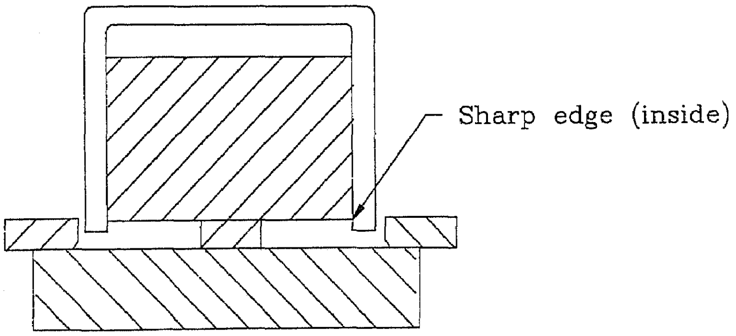
Single bending dies

Various bending operations

Figure 19



PITCH TRIM



HORIZONTAL TRIM

Figure 20

Phase one: Organization
* Define project focus
* Assign responsibilities
* Schedule implementation

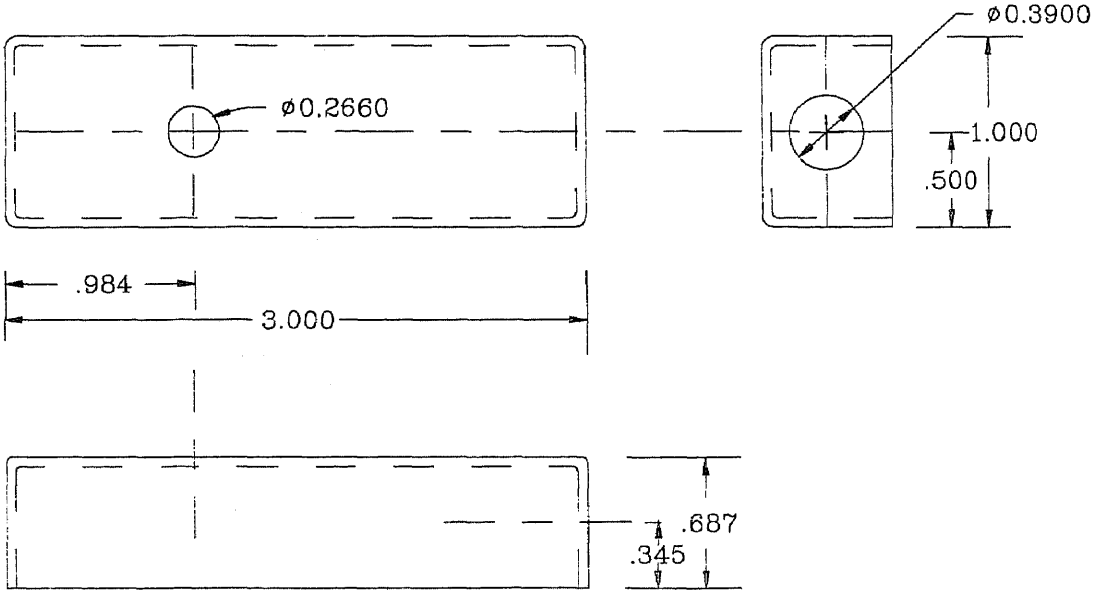
Phase two: Data collection and process capability
* Review historical porcess and product data.
* Review equipment maintenance procedure and records.
* Conduct process capability study

Phase three: Control scheme design
* Determine most effective sampling scheme
* Eliminate unnecessary data collection
* Design control charts, if warranted
* Document changes to current procedures

Phase four: Control scheme implementation
* Train all people in the control feedback scheme.
* Introduce across all areas.
* Periodically monitor effectiveness to update control when warranted.

<u>PHASES FOR STATISTICAL PROCESS CONTROL IMPLEMENTATION</u>

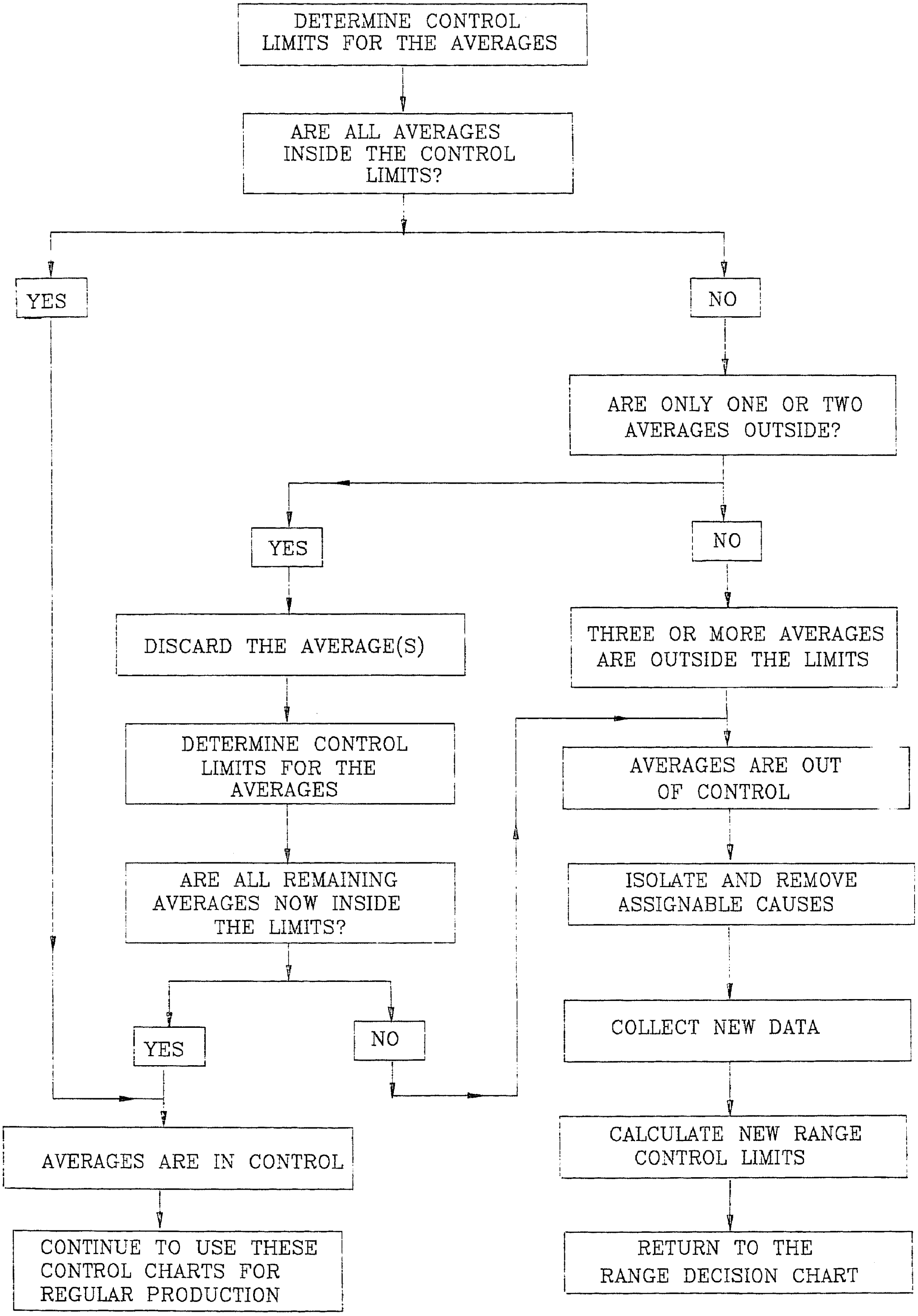
Figure 21



(TOLERANCE: ±.002)

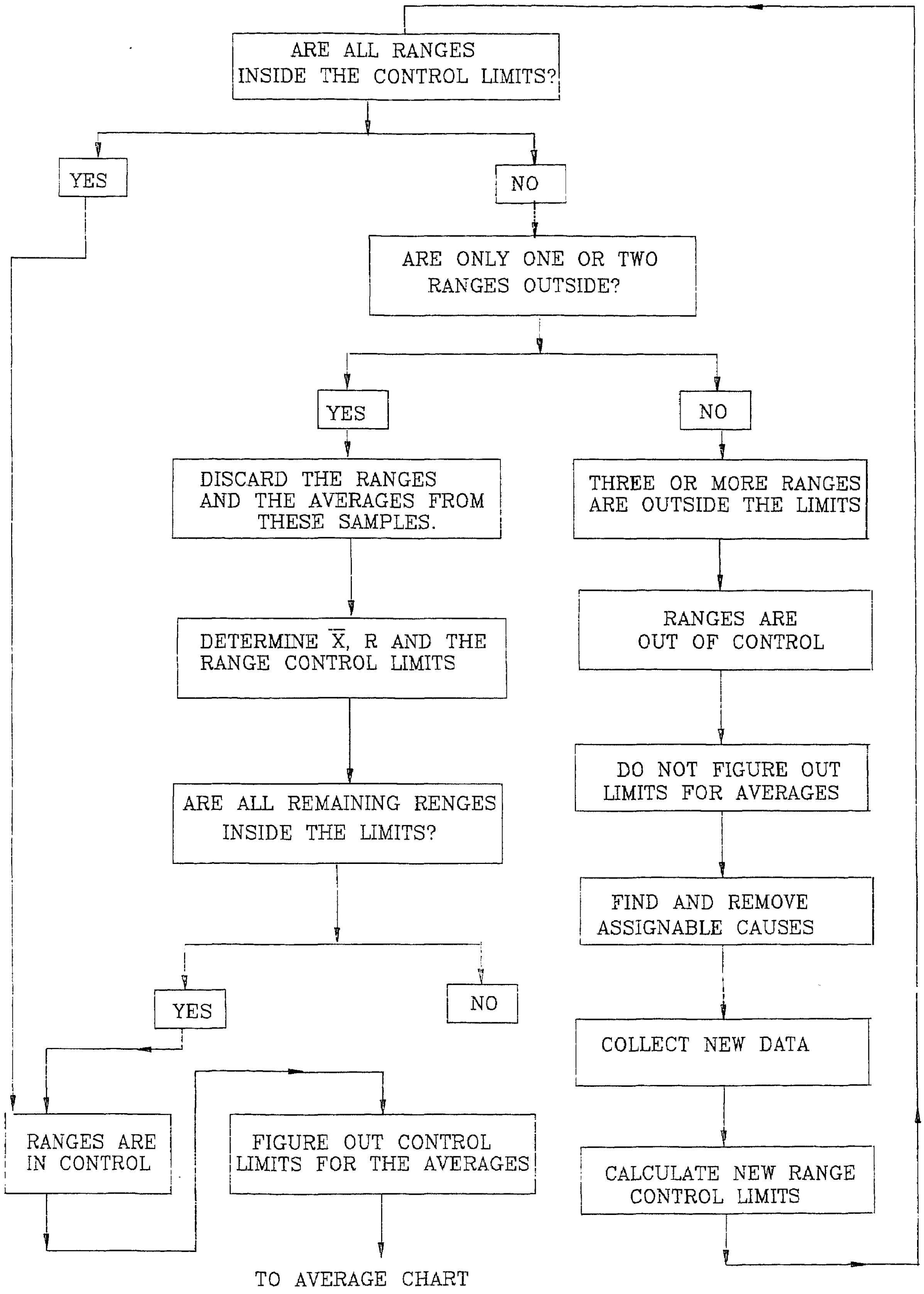
LITTLITE CHASSIS

igure 22



DECISION CHART FOR WORKING WITH AVERAGES

Figure 23



DECISION CHART FOR WORKING WITH THE RANGES

Figure 24

```
     Hudson Tool and Die Co.-Manufacture of littlite chassis
                     LENGTH : X-BAR CHART
     LCL = 2.9977      Center = 2.9993     UCL = 3.0010

Sample         Value   LCL            C            UCL 0  34

-------------------------------------------------------------  ---
SAMPLE   1     2.9977   +    .        |        .    |  0
SAMPLE   2     2.9977   +    .        |        .    |  0
SAMPLE   3     2.9990   |    .     *  |        .    |
SAMPLE   4     2.9997   |    .        |  *     .    |
SAMPLE   5     2.9993   |    .        *        .    |
SAMPLE   6     2.9980   |  * .        |        .    |
SAMPLE   7     2.9980   |  * .        |        .    |
SAMPLE   8     2.9993   |    .        *        .    |
SAMPLE   9     2.9997   |    .        |  *     .    |
SAMPLE  10     3.0000   |    .        |    *   .    |
SAMPLE  11     3.0000   |    .        |    *   .    |
SAMPLE  12     3.0000   |    .        |    *   .    |
SAMPLE  13     2.9993   |    .        *        .    |
SAMPLE  14     3.0003   |    .        |       *.    |
SAMPLE  15     3.0007   |    .        |        . *  |
SAMPLE  16     2.9990   |    .     *  |        .    |
SAMPLE  17     3.0003   |    .        |       *.    |
SAMPLE  18     2.9997   |    .        |  *     .    |
SAMPLE  19     3.0000   |    .        |    *   .    |
SAMPLE  20     2.9993   |    .        *        .    |
-----------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE   1 to SAMPLE   20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

AVERAGE CHART FOR LENGTH OF

LITTLITE CHASSIS

Figure 25

```
     Hudson Tool and Die Co.-Manufacture of littlite chassis
                      LENGTH : RANGE CHART
     LCL = 0.0000      Center = 1.8500E-03  UCL = 4.7612E-03

Sample          Value  LCL         C                UCL 0   34

------------------------------------------------------------------
SAMPLE   1 9.9993E-04    |     *    |          .     |
SAMPLE   2 9.9993E-04    |     *    |          .     |
SAMPLE   3 2.0001E-03    |          |*         .     |
SAMPLE   4 3.0000E-03    |          |      *   .     |
SAMPLE   5 9.9993E-04    |     *    |          .     |
SAMPLE   6 2.0001E-03    |          |*         .     |
SAMPLE   7 2.0001E-03    |          |*         .     |
SAMPLE   8 9.9993E-04    |     *    |          .     |
SAMPLE   9 1.9999E-03    |          |*         .     |
SAMPLE  10 1.9999E-03    |          |*         .     |
SAMPLE  11 1.9999E-03    |          |*         .     |
SAMPLE  12 1.9999E-03    |          |*         .     |
SAMPLE  13 3.0000E-03    |          |      *   .     |
SAMPLE  14 9.9993E-04    |     *    |          .     |
SAMPLE  15 9.9993E-04    |     *    |          .     |
SAMPLE  16 2.0001E-03    |          |*         .     |
SAMPLE  17 9.9993E-04    |     *    |          .     |
SAMPLE  18 3.0000E-03    |          |      *   .     |
SAMPLE  19 1.9999E-03    |          |*         .     |
SAMPLE  20 3.0000E-03    |          |      *   .     |
------------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE    1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the center line
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

RANGE CHART FOR LENGTH OF

LITTLITE CHASSIS

Figure 26

```
     Hudson Tool and Die Co.-Manufacture of littlite chassis
                      HEIGHT : X-BAR CHART
     LCL = 0.9979      Center = 0.9994      UCL = 1.0009

Sample          Value  LCL            C             UCL 0  34


-------------------------------------------------------------------
SAMPLE   1     0.9997   |    .        |  *     .     |
SAMPLE   2     1.0007   |    .        |        .  *  |
SAMPLE   3     0.9993   |    .       *|        .     |
SAMPLE   4     0.9997   |    .        |  *     .     |
SAMPLE   5     0.9990   |    .    *   |        .     |
SAMPLE   6     0.9983   |   *.        |        .     |
SAMPLE   7     0.9983   |   *.        |        .     |
SAMPLE   8     0.9980   |*   .        |        .     |
SAMPLE   9     0.9983   |   *.        |        .     |
SAMPLE  10     0.9997   |    .        |  *     .     |
SAMPLE  11     0.9990   |    .    *   |        .     |
SAMPLE  12     0.9987   |    . *      |        .     |
SAMPLE  13     1.0007   |    .        |        .  *  |
SAMPLE  14     1.0000   |    .        |      * .     |
SAMPLE  15     1.0003   |    .        |        *     |
SAMPLE  16     0.9993   |    .       *|        .     |
SAMPLE  17     1.0000   |    .        |      * .     |
SAMPLE  18     1.0000   |    .        |      * .     |
SAMPLE  19     0.9997   |    .        |  *     .     |
SAMPLE  20     0.9993   |    .       *|        .     |
-------------------------------------------------------------------
 Plan based on 20 valid samples from SAMPLE   1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

AVERAGE CHART FOR HEIGHT OF

LITTLITE CHASSIS

Figure 27

```
     Hudson Tool and Die Co.-Manufacture of littlite chassis
                      HEIGHT : RANGE CHART
     LCL = 0.0000      Center = 1.6000E-03  UCL = 4.1179E-03

Sample          Value  LCL         C              UCL 0  34


----------------------------------------------------------------
SAMPLE   1 9.9999E-04   |      *   |          .     |
SAMPLE   2 1.0000E-03   |      *   |          .     |
SAMPLE   3 9.9999E-04   |      *   |          .     |
SAMPLE   4 9.9999E-04   |      *   |          .     |
SAMPLE   5 2.0000E-03   |          |  *       .     |
SAMPLE   6 9.9999E-04   |      *   |          .     |
SAMPLE   7 9.9999E-04   |      *   |          .     |
SAMPLE   8 2.0000E-03   |          |  *       .     |
SAMPLE   9 9.9999E-04   |      *   |          .     |
SAMPLE  10 3.0000E-03   |          |         *.     |
SAMPLE  11 2.0000E-03   |          |  *       .     |
SAMPLE  12 9.9999E-04   |      *   |          .     |
SAMPLE  13 1.0000E-03   |      *   |          .     |
SAMPLE  14 2.0000E-03   |          |  *       .     |
SAMPLE  15 2.0000E-03   |          |  *       .     |
SAMPLE  16 9.9999E-04   |      *   |          .     |
SAMPLE  17 2.0000E-03   |          |  *       .     |
SAMPLE  18 2.0000E-03   |          |  *       .     |
SAMPLE  19 2.0000E-03   |          |  *       .     |
SAMPLE  20 3.0000E-03   |          |         *.     |

----------------------------------------------------------------
 Plan based on 20 valid samples from SAMPLE   1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

RANGE CHART FOR HEIGHT OF

LITTLITE CHASSIS

Figure 28

```
     Hudson Tool and Die Co.-Manufacture of littlite chassis
                       WDITH : X-BAR CHART
     LCL = 0.6860      Center = 0.6873      UCL = 0.6887

Sample          Value  LCL             C           UCL 0   34

------------------------------------------------------------------
SAMPLE    1     0.6877   |    .         |   *    .    |
SAMPLE    2     0.6867   |    . *       |        .    |
SAMPLE    3     0.6877   |    .         |   *    .    |
SAMPLE    4     0.6877   |    .         |   *    .    |
SAMPLE    5     0.6873   |    .         *        .    |
SAMPLE    6     0.6863   |   *.         |        .    |
SAMPLE    7     0.6877   |    .         |   *    .    |
SAMPLE    8     0.6873   |    .         *        .    |
SAMPLE    9     0.6863   |   *.         |        .    |
SAMPLE   10     0.6870   |    .     *   |        .    |
SAMPLE   11     0.6873   |    .         *        .    |
SAMPLE   12     0.6883   |    .         |        . *  |
SAMPLE   13     0.6873   |    .         *        .    |
SAMPLE   14     0.6887   |    .         |        .    *
SAMPLE   15     0.6880   |    .         |      * .    |
SAMPLE   16     0.6867   |    . *       |        .    |
SAMPLE   17     0.6870   |    .     *   |        .    |
SAMPLE   18     0.6873   |    .         *        .    |
SAMPLE   19     0.6877   |    .         |   *    .    |
SAMPLE   20     0.6863   |   *.         |        .    |

------------------------------------------------------------------
 Plan based on 20 valid samples from SAMPLE   1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

AVERAGE CHART FOR WIDTH OF

LITTLITE CHASSIS

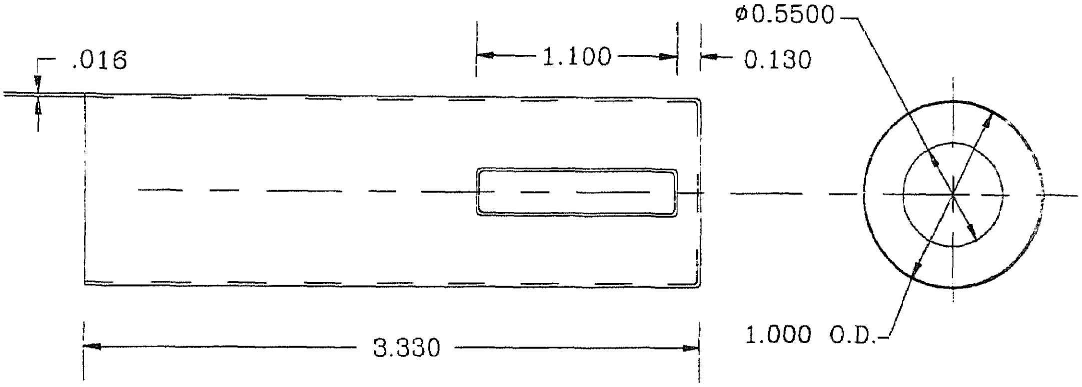
Figure 29

```
     Hudson Tool and Die Co.-Manufacture of littlite chassis
                      WDITH : RANGE CHART
     LCL = 0.0000     Center = 1.4000E-03  UCL = 3.6032E-03

Sample         Value  LCL         C               UCL  0  34

-----------------------------------------------------------------
SAMPLE   1 1.0000E-03   |       *  |          .     |
SAMPLE   2 2.0000E-03   |          |    *     .     |
SAMPLE   3 1.0000E-03   |       *  |          .     |
SAMPLE   4 1.0000E-03   |       *  |          .     |
SAMPLE   5 1.0000E-03   |       *  |          .     |
SAMPLE   6 9.9999E-04   |       *  |          .     |
SAMPLE   7 1.0000E-03   |       *  |          .     |
SAMPLE   8 2.0000E-03   |          |    *     .     |
SAMPLE   9 9.9999E-04   |       *  |          .     |
SAMPLE  10 2.0000E-03   |          |    *     .     |
SAMPLE  11 3.0000E-03   |          |          . *   |
SAMPLE  12 9.9999E-04   |       *  |          .     |
SAMPLE  13 1.0000E-03   |       *  |          .     |
SAMPLE  14 9.9999E-04   |       *  |          .     |
SAMPLE  15 3.0000E-03   |          |          . *   |
SAMPLE  16 9.9999E-04   |       *  |          .     |
SAMPLE  17 2.0000E-03   |          |    *     .     |
SAMPLE  18 1.0000E-03   |       *  |          .     |
SAMPLE  19 1.0000E-03   |       *  |          .     |
SAMPLE  20 9.9999E-04   |       *  |          .     |

-----------------------------------------------------------------
 Plan based on 20 valid samples from SAMPLE    1 to SAMPLE   20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

RANGE CHART FOR WIDTH OF

LITTLITE CHASIS

Figure 30



SLOTTED CANE

NOTE:
1. 2 EQUALLY SPACED SLOTS, 45° APART
2. TOLERANCE ±0.002

Figure 31

```
       Hudson Tool and Die Co.-Manufacture of slotted cans
                     THICKNESS : X-BAR CHART
     LCL = 0.0147      Center = 0.0159    UCL = 0.0170

Sample          Value  LCL           C           UCL 0   34

--------------------------------------------------------------
SAMPLE   1     0.0153   |    . *     |       .    |
SAMPLE   2     0.0153   |    . *     |       .    |
SAMPLE   3     0.0157   |    .     * |       .    |
SAMPLE   4     0.0157   |    .     * |       .    |
SAMPLE   5     0.0157   |    .     * |       .    |
SAMPLE   6     0.0167   |    .       |       .*   |
SAMPLE   7     0.0157   |    .     * |       .    |
SAMPLE   8     0.0153   |    . *     |       .    |
SAMPLE   9     0.0153   |    . *     |       .    |
SAMPLE  10     0.0153   |    . *     |       .    |
SAMPLE  11     0.0163   |    .       |    *  .    |
SAMPLE  12     0.0170   |    .       |       .    *
SAMPLE  13     0.0163   |    .       |    *  .    |
SAMPLE  14     0.0160   |    .       | *     .    |
SAMPLE  15     0.0167   |    .       |       .*   |
SAMPLE  16     0.0153   |    . *     |       .    |
SAMPLE  17     0.0163   |    .       |    *  .    |
SAMPLE  18     0.0157   |    .     * |       .    |
SAMPLE  19     0.0153   |    . *     |       .    |
SAMPLE  20     0.0160   |    .       | *     .    |

--------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE    1 to SAMPLE   20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

AVERAGE CHART FOR THICKNESS OF

SLOTTED CAN

Figure 32

```
       Hudson Tool and Die Co.-Manufacture of slotted cans
                     THICKNESS : RANGE CHART
     LCL = 0.0000      Center = 1.3500E-03  UCL = 3.4745E-03

Sample          Value  LCL         C               UCL 0  34

------------------------------------------------------------------
SAMPLE   1 1.0000E-03    |       *  |          .     |
SAMPLE   2 2.0000E-03    |          |    *     .     |
SAMPLE   3 1.0000E-03    |       *  |          .     |
SAMPLE   4 1.0000E-03    |       *  |          .     |
SAMPLE   5 2.0000E-03    |          |    *     .     |
SAMPLE   6 1.0000E-03    |       *  |          .     |
SAMPLE   7 2.0000E-03    |          |    *     .     |
SAMPLE   8 1.0000E-03    |       *  |          .     |
SAMPLE   9 1.0000E-03    |       *  |          .     |
SAMPLE  10 1.0000E-03    |       *  |          .     |
SAMPLE  11 1.0000E-03    |       *  |          .     |
SAMPLE  12 2.0000E-03    |          |    *     .     |
SAMPLE  13 1.0000E-03    |       *  |          .     |
SAMPLE  14 2.0000E-03    |          |    *     .     |
SAMPLE  15 1.0000E-03    |       *  |          .     |
SAMPLE  16 1.0000E-03    |       *  |          .     |
SAMPLE  17 2.0000E-03    |          |    *     .     |
SAMPLE  18 1.0000E-03    |       *  |          .     |
SAMPLE  19 1.0000E-03    |       *  |          .     |
SAMPLE  20 2.0000E-03    |          |    *     .     |
------------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE   1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

RANGE CHART FOR THICKNESS OF

SLOTTED CAN

Figure 33

```
              Hudson Tool and Die Co.-Manufacture of slotted cans
                              HEIGHT : X-BAR CHART
        LCL = 0.1285       Center = 0.1299      UCL = 0.1312

Sample              Value  LCL            C            UCL 0   34

-------------------------------------------------------------------
SAMPLE    1    0.1293   |    .  *     |       .    |
SAMPLE    2    0.1293   |    .  *     |       .    |
SAMPLE    3    0.1293   |    .  *     |       .    |
SAMPLE    4    0.1290   |    *        |       .    |
SAMPLE    5    0.1297   |    .      * |       .    |
SAMPLE    6    0.1300   |    .        |*      .    |
SAMPLE    7    0.1287   |*   .        |       .    |
SAMPLE    8    0.1293   |    .  *     |       .    |
SAMPLE    9    0.1293   |    .  *     |       .    |
SAMPLE   10    0.1307   |    .        |      *.    |
SAMPLE   11    0.1307   |    .        |      *.    |
SAMPLE   12    0.1310   |    .        |       .  * |
SAMPLE   13    0.1307   |    .        |      *.    |
SAMPLE   14    0.1300   |    .        |*      .    |
SAMPLE   15    0.1310   |    .        |       .  * |
SAMPLE   16    0.1297   |    .      * |       .    |
SAMPLE   17    0.1300   |    .        |*      .    |
SAMPLE   18    0.1297   |    .      * |       .    |
SAMPLE   19    0.1293   |    .  *     |       .    |
SAMPLE   20    0.1307   |    .        |      *.    |
-------------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE    1 to SAMPLE   20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

AVERAGE CHART FOR HEIGHT OF

SLOTTED CAN

Figure 34

```
       Hudson Tool and Die Co.-Manufacture of slotted cans
                      HEIGHT : RANGE CHART
     LCL = 0.0000       Center = 1.4000E-03  UCL = 3.6032E-03

Sample          Value  LCL         C               UCL 0  34

------------------------------------------------------------------
SAMPLE   1 1.0000E-03   |       *  |          .      |
SAMPLE   2 1.0000E-03   |       *  |          .      |
SAMPLE   3 1.0000E-03   |       *  |          .      |
SAMPLE   4 2.0000E-03   |          |    *     .      |
SAMPLE   5 1.0000E-03   |       *  |          .      |
SAMPLE   6 2.0000E-03   |          |    *     .      |
SAMPLE   7 2.0000E-03   |          |    *     .      |
SAMPLE   8 1.0000E-03   |       *  |          .      |
SAMPLE   9 1.0000E-03   |       *  |          .      |
SAMPLE  10 1.0000E-03   |       *  |          .      |
SAMPLE  11 1.0000E-03   |       *  |          .      |
SAMPLE  12 2.0000E-03   |          |    *     .      |
SAMPLE  13 1.0000E-03   |       *  |          .      |
SAMPLE  14 2.0000E-03   |          |    *     .      |
SAMPLE  15 2.0000E-03   |          |    *     .      |
SAMPLE  16 2.0000E-03   |          |    *     .      |
SAMPLE  17 2.0000E-03   |          |    *     .      |
SAMPLE  18 1.0000E-03   |       *  |          .      |
SAMPLE  19 1.0000E-03   |       *  |          .      |
SAMPLE  20 1.0000E-03   |       *  |          .      |
------------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE   1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

<u>RANGE CHART FOR HEIGHT OF</u>

<u>SLOTTED CAN</u>

Figure 35

```
      Hudson Tool and Die Co.-Manufacture of slotted cans
                        LENGTH :  `-BAR CHART
     LCL = 1.0980       Center   1.1000      UCL = 1.1020

Sample          Value  LCL             C            UCL 0  34

------------------------------------------------------------------
SAMPLE   1     1.1003    |    .        |  *      .    |
SAMPLE   2     1.1000    |    .        *         .    |
SAMPLE   3     1.1000    |    .        *         .    |
SAMPLE   4     1.0993    |    .   *    |         .    |
SAMPLE   5     1.0993    |    .   *    |         .    |
SAMPLE   6     1.1000    |    .        *         .    |
SAMPLE   7     1.1000    |    .        *         .    |
SAMPLE   8     1.1003    |    .        |  *      .    |
SAMPLE   9     1.0997    |    .      * |         .    |
SAMPLE  10     1.1000    |    .        *         .    |
SAMPLE  11     1.0993    |    .   *    |         .    |
SAMPLE  12     1.1003    |    .        |  *      .    |
SAMPLE  13     1.1010    |    .        |       * .    |
SAMPLE  14     1.1000    |    .        *         .    |
SAMPLE  15     1.1010    |    .        |       * .    |
SAMPLE  16     1.0997    |    .      * |         .    |
SAMPLE  17     1.1003    |    .        |  *      .    |
SAMPLE  18     1.0997    |    .      * |         .    |
SAMPLE  19     1.0993    |    .   *    |         .    |
SAMPLE  20     1.1003    |    .        |  *      .    |
------------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE   1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

AVERAGE CHART FOR SLOT LENGTH OF

SLOTTED CAN

Figure 36

```
         Hudson Tool and Die Co.-Manufacture of slotted cans
                         LENGTH : RANGE CHART
     LCL = 0.0000       Center = 2.1000E-03  UCL = 5.4048E-03

Sample          Value  LCL         C               UCL 0   34

-----------------------------------------------------------------
SAMPLE   1 9.9993E-04   |    *     |          .     |
SAMPLE   2 3.0000E-03   |          |    *     .     |
SAMPLE   3 2.0000E-03   |         *|          .     |
SAMPLE   4 1.0000E-03   |    *     |          .     |
SAMPLE   5 2.0000E-03   |         *|          .     |
SAMPLE   6 2.0000E-03   |         *|          .     |
SAMPLE   7 3.0000E-03   |          |    *     .     |
SAMPLE   8 3.0000E-03   |          |    *     .     |
SAMPLE   9 1.0000E-03   |    *     |          .     |
SAMPLE  10 3.0000E-03   |          |    *     .     |
SAMPLE  11 1.0000E-03   |    *     |          .     |
SAMPLE  12 3.0000E-03   |          |    *     .     |
SAMPLE  13 2.0000E-03   |         *|          .     |
SAMPLE  14 3.0000E-03   |          |    *     .     |
SAMPLE  15 2.0000E-03   |         *|          .     |
SAMPLE  16 1.0000E-03   |    *     |          .     |
SAMPLE  17 9.9993E-04   |    *     |          .     |
SAMPLE  18 2.0000E-03   |         *|          .     |
SAMPLE  19 2.9999E-03   |          |    *     .     |
SAMPLE  20 3.0000E-03   |          |    *     .     |

-----------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE    1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

RANGE CHART FOR SLOT LENGTH OF

SLOTTED CAN

Figure 37

```
       Hudson Tool and Die Co.-Manufacture of slotted cans
                     HOLE DIA. : RANGE CHART
     LCL = 0.0000      Center = 1.4500E-03  UCL = 3.7318E-03

Sample          Value  LCL         C               UCL 0  34

-----------------------------------------------------------------
SAMPLE   1 9.9999E-04   |       *  |          .     |
SAMPLE   2 9.9999E-04   |       *  |          .     |
SAMPLE   3 2.0000E-03   |          |   *      .     |
SAMPLE   4 2.0000E-03   |          |   *      .     |
SAMPLE   5 9.9999E-04   |       *  |          .     |
SAMPLE   6 2.0000E-03   |          |   *      .     |
SAMPLE   7 9.9999E-04   |       *  |          .     |
SAMPLE   8 2.0000E-03   |          |   *      .     |
SAMPLE   9 9.9999E-04   |       *  |          .     |
SAMPLE  10 9.9999E-04   |       *  |          .     |
SAMPLE  11 2.0000E-03   |          |   *      .     |
SAMPLE  12 2.0000E-03   |          |   *      .     |
SAMPLE  13 1.0000E-03   |       *  |          .     |
SAMPLE  14 2.0000E-03   |          |   *      .     |
SAMPLE  15 9.9999E-04   |       *  |          .     |
SAMPLE  16 9.9999E-04   |       *  |          .     |
SAMPLE  17 9.9999E-04   |       *  |          .     |
SAMPLE  18 9.9999E-04   |       *  |          .     |
SAMPLE  19 2.0000E-03   |          |   *      .     |
SAMPLE  20 2.0000E-03   |          |   *      .     |
-----------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE   1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

RANGE CHART FOR HOLE DIAMETER OF SLOTTED CAN

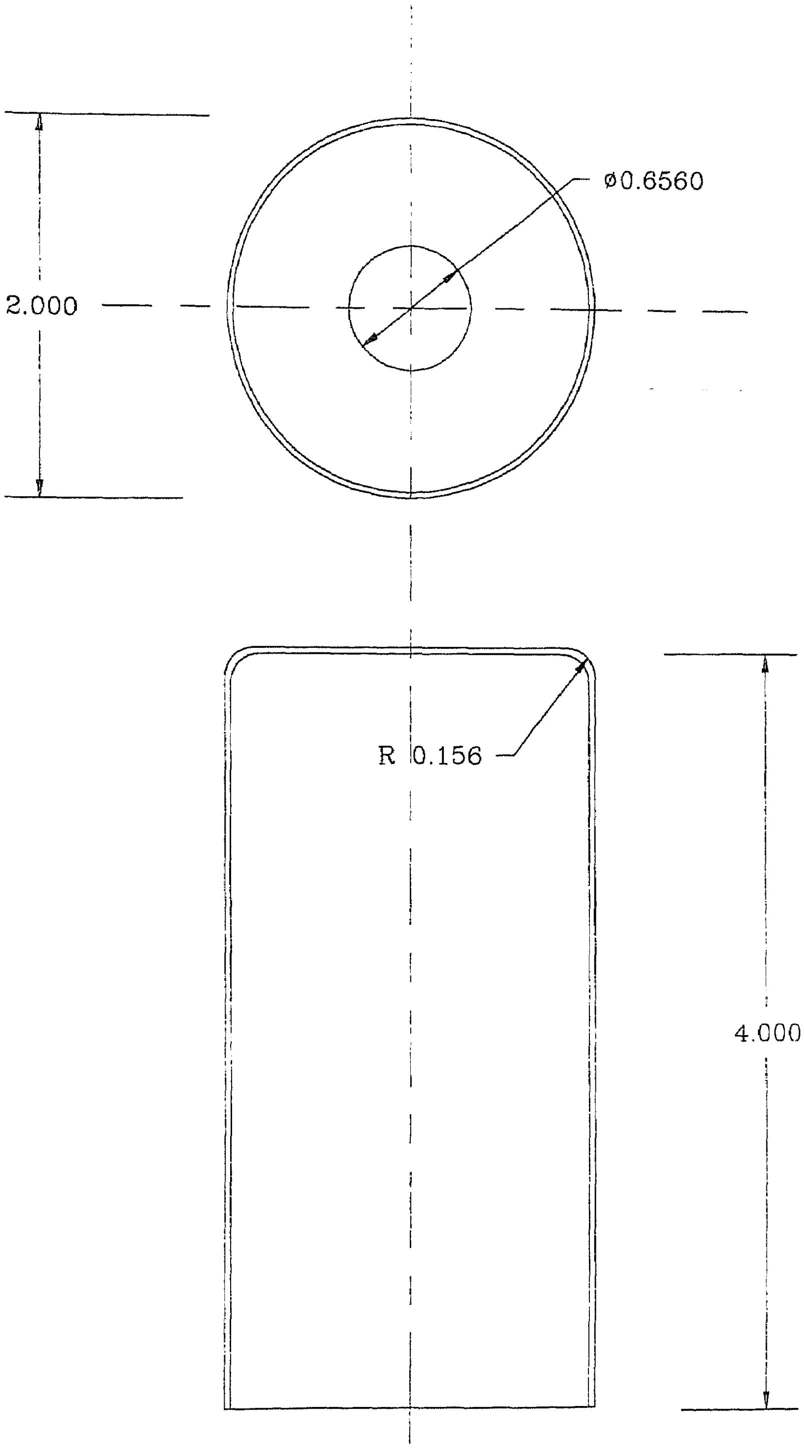
Figure 38

```
       Hudson Tool and Die Co.-Manufacture of slotted cans
                     HOLE DIA. : X-BAR CHART
     LCL = 0.5487          Center = 0.5500      UCL = 0.5513

Sample           Value  LCL          C            UCL 0  34


----------------------------------------------------------------
SAMPLE   1     0.5507   |    .        |     * .    |
SAMPLE   2     0.5503   |    .        |  *    .    |
SAMPLE   3     0.5500   |    .        *       .    |
SAMPLE   4     0.5500   |    .        *       .    |
SAMPLE   5     0.5507   |    .        |     * .    |
SAMPLE   6     0.5500   |    .        *       .    |
SAMPLE   7     0.5507   |    .        |     * .    |
SAMPLE   8     0.5500   |    .        *       .    |
SAMPLE   9     0.5503   |    .        |  *    .    |
SAMPLE  10     0.5497   |    .    *   |       .    |
SAMPLE  11     0.5500   |    .        *       .    |
SAMPLE  12     0.5490   |  * .        |       .    |
SAMPLE  13     0.5487   +    .        |       .    |  0
SAMPLE  14     0.5500   |    .        *       .    |
SAMPLE  15     0.5507   |    .        |     * .    |
SAMPLE  16     0.5497   |    .    *   |       .    |
SAMPLE  17     0.5493   |    . *      |       .    |
SAMPLE  18     0.5503   |    .        |  *    .    |
SAMPLE  19     0.5500   |    .        *       .    |
SAMPLE  20     0.5500   |    .        *       .    |
----------------------------------------------------------------

 Plan based on 20 valid samples from SAMPLE   1 to SAMPLE  20

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

AVERAGE CHART FOR HOLE DIAMETER OF

SLOTTED CAN

Figure 39



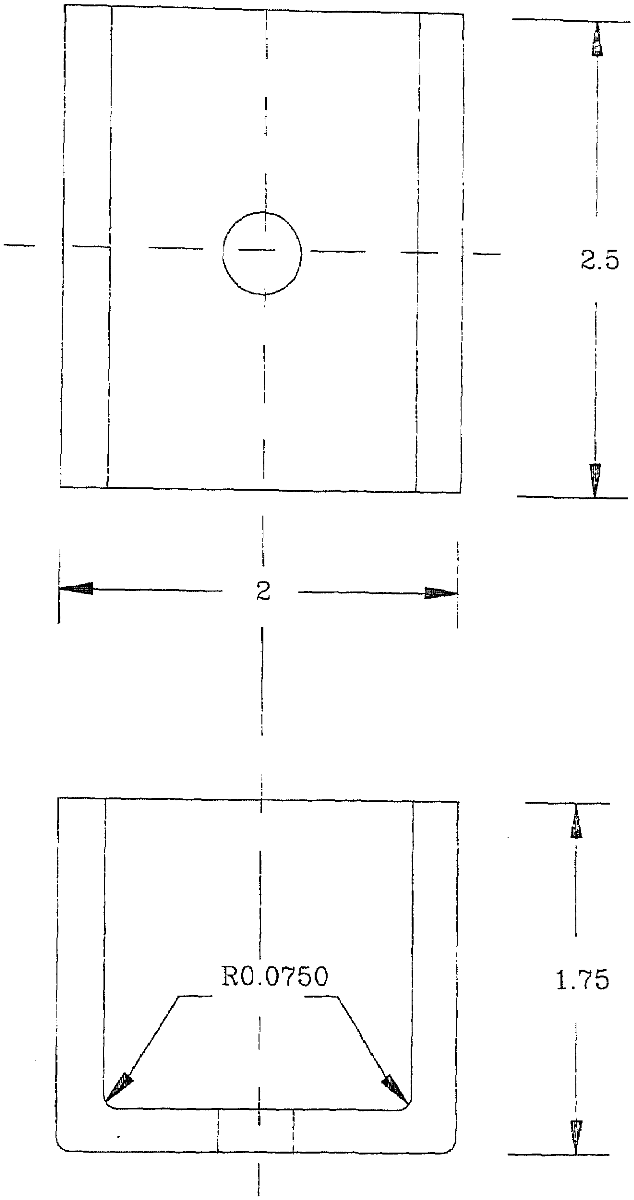
COVER (TOLERANCE: ±.001)

Figure 40

```
     LCL = 0.0000        Center = 0.1520        UCL = 0.6000
Sample          Value  LCL    C                  UCL 0   34

-----------------------------------------------------------------
SAMPLE   1     0.2000   |      | *                |
SAMPLE   2     0.3000   |      |     *            |
SAMPLE   3     0.2000   |      | *                |
SAMPLE   4     0.1000   |    * |                  |
SAMPLE   5     0.0000   *      |                  |
SAMPLE   6     0.2000   |      | *                |
SAMPLE   7     0.4000   |      |         *        |
SAMPLE   8     0.3000   |      |     *            |
SAMPLE   9     0.1000   |    * |                  |
SAMPLE  10     0.0000   *      |                  |
SAMPLE  11     0.1000   |    * |                  |
SAMPLE  12     0.2000   |      | *                |
SAMPLE  13     0.1000   |    * |                  |
SAMPLE  14     0.0000   *      |                  |
SAMPLE  15     0.2000   |      | *                |
SAMPLE  16     0.3000   |      |     *            |
SAMPLE  17     0.0000   *      |                  |
SAMPLE  18     0.1000   |    * |                  |
SAMPLE  19     0.1000   |    * |                  |
SAMPLE  20     0.1000   |    * |                  |
SAMPLE  21     0.0000   *      |                  |
SAMPLE  22     0.2000   |      | *                |
SAMPLE  23     0.3000   |      |     *            |
SAMPLE  24     0.2000   |      | *                |
SAMPLE  25     0.1000   |    * |                  |
-----------------------------------------------------------------
```

p-CHART FOR COVER

Figure 41



U-BEND

Figure 42

```
         LCL = 0.0735     Center = 0.0747      UCL = 0.0758

    Sample         Value  LCL            C            UCL 0   34

    ------------------------------------------------------------------
    SAMPLE   1    0.0720    +    .        |       .    |  0
    SAMPLE   2    0.0740    |    .*       |       .    |
    SAMPLE   3    0.0747    |    .        *       .    |
    SAMPLE   4    0.0753    |    .        |      *.    |
    SAMPLE   5    0.0740    |    .*       |       .    |
    SAMPLE   6    0.0753    |    .        |      *.    |
    SAMPLE   7    0.0743    |    .    *   |       .    |
    SAMPLE   8    0.0753    |    .        |      *.    |
    SAMPLE   9    0.0743    |    .    *   |       .    |
    SAMPLE  10    0.0747    |    .        *       .    |
    SAMPLE  11    0.0750    |    .        |   *   .    |
    SAMPLE  12    0.0757    |    .        |       .  * |
    SAMPLE  13    0.0747    |    .        *       .  . |
    SAMPLE  14    0.0753    |    .        |      *.    |
    SAMPLE  15    0.0737    | *  .        |       .    |
    SAMPLE  16    0.0743    |    .    *   |       .    |
    SAMPLE  17    0.0750    |    .        |   *   .    |
    SAMPLE  18    0.0753    |    .        |      *.    |
    SAMPLE  19    0.0746    |    .        *       .    |
    SAMPLE  20    0.0750    |    .        |    *  .    |
    SAMPLE  21    0.0740    |    .*       |       .    |
    SAMPLE  22    0.0747    |    .        |*      .    |
    SAMPLE  23    0.0753    |    .        |      *.    |
    SAMPLE  24    0.0746    |    .        *       .    |
    SAMPLE  25    0.0750    |    .        |   *   .    |
    ------------------------------------------------------------------
```

```
            Hudson Tool & Die Co.- U-Bend manufacture
                      RADIUS : X-BAR CHART
     LCL = 0.0735      Center = 0.0747      UCL = 0.0758

Sample          Value  LCL            C            UCL 0   34

 Plan based on 25 valid samples from SAMPLE   1 to SAMPLE  25

 Sig. Prob. for Chi-Squared test on history range = 0.3679

 0   Points outside control limits
 3   Run of 7 or more above/below the centerline
 4   Run of 7 or more up or down

 A   Assignable cause
 M   Missing value
```

AVERAGE CHART FOR RADIUS OF U-BEND

Figure 43

```
                   Hudson Tool & Die Co.- U-Bend manufacture
                             RADIUS : RANGE CHART
          LCL = 0.0000      Center = 1.2160E-03  UCL = 3.1296E-03

Sample            Value  LCL         C               UCL 0  34

-----------------------------------------------------------------------
SAMPLE     1 2.0000E-03   |          |      *   .     |
SAMPLE     2 2.0000E-03   |          |      *   .     |
SAMPLE     3 1.0000E-03   |        * |          .     |
SAMPLE     4 3.0000E-03   |          |          .    *|
SAMPLE     5     0.0000   *          |          .     |
SAMPLE     6 9.9999E-04   |        * |          .     |
SAMPLE     7 2.0000E-03   |          |      *   .     |
SAMPLE     8 9.9999E-04   |        * |          .     |
SAMPLE     9 1.0000E-03   |        * |          .     |
SAMPLE    10 1.0000E-03   |        * |          .     |
SAMPLE    11 2.0000E-03   |          |      *   .     |
SAMPLE    12 9.9999E-04   |        * |          .     |
SAMPLE    13 1.0000E-03   |        * |          .     |
SAMPLE    14 9.9999E-04   |        * |          .     |
SAMPLE    15 1.0000E-03   |        * |          .     |
SAMPLE    16 1.0000E-03   |        * |          .     |
SAMPLE    17 2.0000E-03   |          |      *   .     |
SAMPLE    18 9.9999E-04   |        * |          .     |
SAMPLE    19 1.0000E-03   |        * |          .     |
SAMPLE    20 9.9994E-05   |*         |          .     |
SAMPLE    21 2.0000E-03   |          |      *   .     |
SAMPLE    22 1.1000E-03   |         *|          .     |
SAMPLE    23 9.9999E-04   |        * |          .     |
SAMPLE    24 1.0000E-03   |        * |          .     |
SAMPLE    25 2.0000E-04   | *        |          .     |
-----------------------------------------------------------------------
```

RANGE CHART FOR RADIUS OF U-BEND

Figure 44

```
            Hudson Tool & Die Co.- U-Bend manufacture
                      HEIGHT : X-BAR CHART
     LCL = 1.7481      Center = 1.7498      UCL = 1.7516

Sample          Value  LCL             C            UCL 0  34

-------------------------------------------------------------------
SAMPLE    1    1.7493    |    .    *   |        .    |
SAMPLE    2    1.7497    |    .       *|        .    |
SAMPLE    3    1.7503    |    .        |   *    .    |
SAMPLE    4    1.7497    |    .       *|        .    |
SAMPLE    5    1.7503    |    .        |   *    .    |
SAMPLE    6    1.7490    |    . *      |        .    |
SAMPLE    7    1.7503    |    .        |   *    .    |
SAMPLE    8    1.7497    |    .       *|        .    |
SAMPLE    9    1.7503    |    .        |   *    .    |
SAMPLE   10    1.7490    |    . *      |        .    |
SAMPLE   11    1.7500    |    .        |*       .    |
SAMPLE   12    1.7490    |    . *      |        .    |
SAMPLE   13    1.7503    |    .        |   *    .    |
SAMPLE   14    1.7500    |    .        |*       .    |
SAMPLE   15    1.7493    |    .    *   |        .    |
SAMPLE   16    1.7503    |    .        |   *    .    |
SAMPLE   17    1.7493    |    .    *   |        .    |
SAMPLE   18    1.7503    |    .        |   *    .    |
SAMPLE   19    1.7497    |    .       *|        .    |
SAMPLE   20    1.7503    |    .        |   *    .    |
SAMPLE   21    1.7500    |    .        |*       .    |
SAMPLE   22    1.7497    |    .       *|        .    |
SAMPLE   23    1.7500    |    .        |*       .    |
SAMPLE   24    1.7497    |    .       *|        .    |
SAMPLE   25    1.7500    |    .        |*       .    |
-------------------------------------------------------------------
```

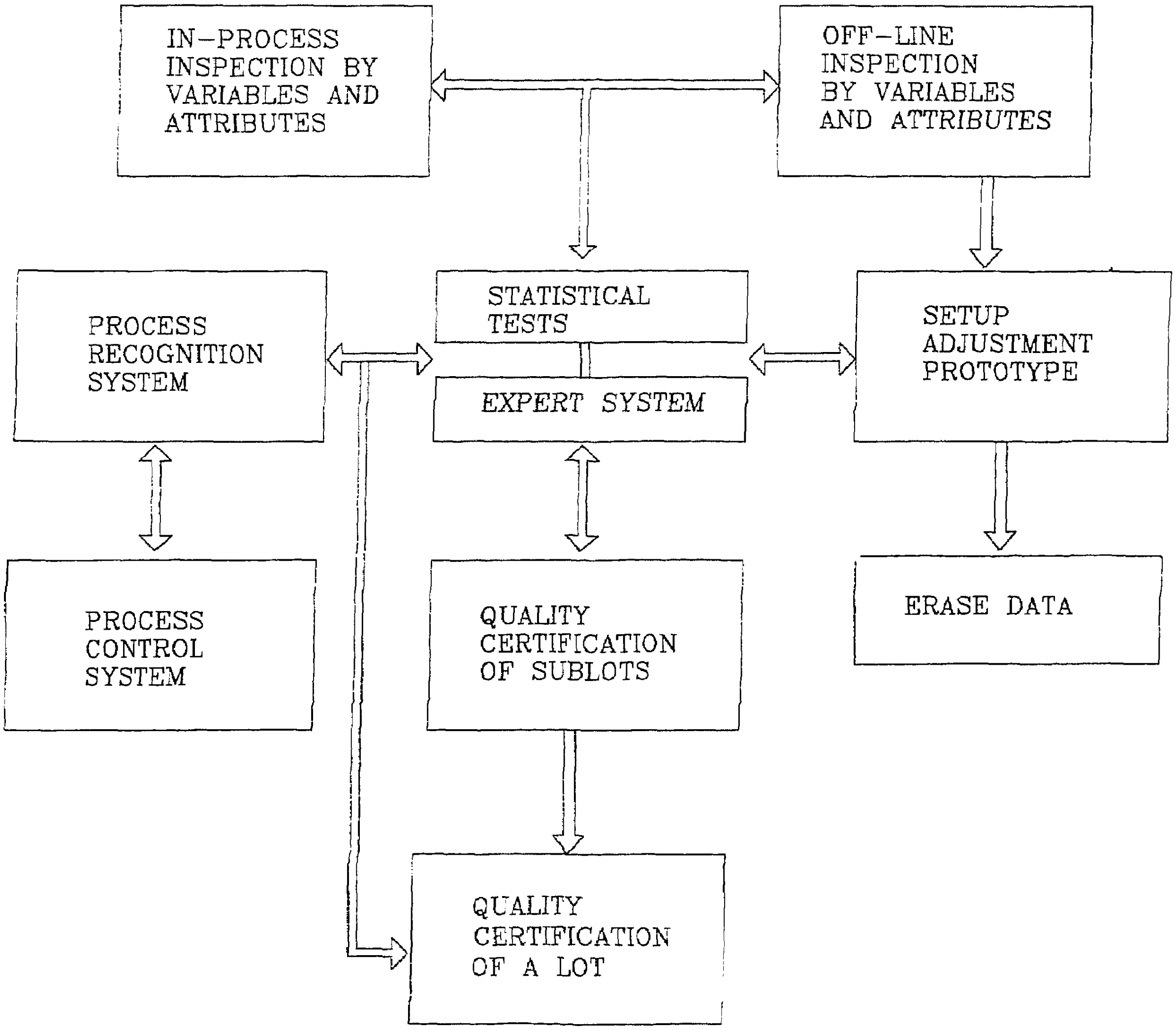
AVERAGE CHART FOR HEIGHT OF U-BEND

Figure 45

```
            Hudson Tool & Die Co. - U-Bend manufacture
                      HEIGHT : RANGE CHART
     LCL = 0.0000      Center = 1.8400E-03  UCL = 4.7357E-03

Sample          Value  LCL        C               UCL 0   34

----------------------------------------------------------------
SAMPLE   1 2.0000E-03   |          |*         .    |
SAMPLE   2 1.0000E-03   |     *    |          .    |
SAMPLE   3 1.0000E-03   |     *    |          .    |
SAMPLE   4 1.0000E-03   |     *    |          .    |
SAMPLE   5 3.9999E-03   |          |          . *  |
SAMPLE   6 2.0000E-03   |          |*         .    |
SAMPLE   7 1.0000E-03   |     *    |          .    |
SAMPLE   8 2.0001E-03   |          |*         .    |
SAMPLE   9 2.0001E-03   |          |*         .    |
SAMPLE  10 2.0000E-03   |          |*         .    |
SAMPLE  11 2.0001E-03   |          |*         .    |
SAMPLE  12 2.0000E-03   |          |*         .    |
SAMPLE  13 3.0000E-03   |          |      *   .    |
SAMPLE  14     0.0000   *          |          .    |
SAMPLE  15 3.0000E-03   |          |      *   .    |
SAMPLE  16 1.0000E-03   |     *    |          .    |
SAMPLE  17 1.0000E-03   |     *    |          .    |
SAMPLE  18 2.0001E-03   |          |*         .    |
SAMPLE  19 2.0001E-03   |          |*         .    |
SAMPLE  20 2.0001E-03   |          |*         .    |
SAMPLE  21 2.0001E-03   |          |*         .    |
SAMPLE  22 1.0000E-03   |     *    |          .    |
SAMPLE  23 2.0001E-03   |          |*         .    |
SAMPLE  24 2.0001E-03   |          |*         .    |
SAMPLE  25 3.0000E-03   |          |      *   .    |
----------------------------------------------------------------
```

<u>RANGE CHART FOR HEIGHT OF U-BEND</u>

Figure 46



EXPERT SYSTEM BASED SPC SOFTWARE

Figure 47