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Drop Weight Testing Rig Analysis and Design

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ABSTRACT

Crashworthiness studies are becoming increasingly important in mechanical design, particularly with the new advancement of the computer simulation codes. These studies generally require material and prototype testing for both modelling and validation. Large percentages of these studies lie on the limits of medium strain rate, which could be achieved by a drop weight test rig. Therefore, the drop weight test rig becomes an essential tool for such research activities besides the universal quasi-static testing machines. This paper is devoted to the analysis and design of the drop weight impact-testing rig. First, the different aspects of the mechanical design such as the propulsion, guidance, and frame layout, foundation and energy aspects are presented and discussed. Then, the basic types of data retrieval and analysis systems applicable for drop weight impact testing machines are presented and discussed. Data retrieval components considered in this study include the sensors for load, acceleration, and velocity measurements, image acquisition including high-speed cameras and PC-based image acquisition system, and data acquisition including oscilloscope or PC-based data acquisition system which utilizes an A/D card and application software for visualizing and analyzing of the results. At the end of this article the designed and constructed test machine is presented as a case study.

Keywords: Drop weight, impact, strain rate, low velocity, crashworthiness, helmet

INTRODUCTION

In this article the drop weight design requirements in general are presented. However, more emphasis is given to crashworthiness testing requirements or similar application. This needs a clarification here for distinguishing from other drop weight applications such as that for metal forming.

Therefore, the basic requirements and the general guidelines for the design of drop weight testing rig will be presented and discussed in this article and case study of drop weight test rig which is designed and constructed for helmet testing and similar applications will be briefly described.

In general, if a drop weight testing rig is required by a crashworthiness laboratory, there would be two ways to fulfill this requirement. The first is to purchase a general purpose prefabricated testing rig from specialized suppliers such as Dynatup or QUALTITEST (see references), and the second is to carry out the design and fabrication in-house. The first alternative is more reliable, as performance is usually guaranteed by suppliers, but is expensive and working space is limited. The second alternative is economical and can be made with a large degree of flexibility, but professional personnel especially in electronic equipment installation and commissioning is a must. In fact, according to the authors' knowledge, there is no review or design article, which

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is directly devoted to this issue. In a survey on the drop weight rigs available in related research works, it was found that various configurations and designs were used for crashworthiness studies (Clements *et al.* 1988; Combet *et al.* 1998; Volt *et al.* 1998; Zho 1998; Broutman and Rottem 1975; Colakoglu and Yildirius 1993; Lee *et al.* 1998; Ambur *et al.* 1995, Kowalski *et al.* 1999; Nazar *et al.* 1996). This could give an impression that in most of those rigs the second choice, which is the in-house built rig, might have been employed due to the reasons mentioned.

DESIGN SPECIFICATION & REQUIREMENTS

Basic Mechanical Requirments

Drop weight tester, in contrast to other impact testing apparatus can be made in variety of ways without appreciably altering the results of test results. The drop weight tester shall be any suitable apparatus that conforms to the following requirements:

- Permit accurate pre-positioning of the test specimen to assure free falling and impact at the exact place and in the direction desired.
- Permit accurate and convenient control of the height of the drop.
- Permit a free unobstructed fall.
- Provide a solid surface of concrete, or steel of sufficient mass to absorb all the expected shocks without appreciable deformation or energy losses.

As mentioned previously, drop weight tester has not been standardized yet, therefore, several configurations with minor variations are found in the literature. These variations depend on the intended application. For example, a high-speed camera may be required for test rig for academic study purposes but not for inspection (qualifying) requirements.

Macaulay (1985) highlighted most of the basic requirements for low velocity impact drop weight tester. However, his information was presented in a general manner and did not specify any particular application. For example, the range of low velocity impact, which could be produced by drop weight tester, was stated to be from 1 to 20 m/s. This does not mean that the total range would be applicable to all crashworthiness studies. The applicable range for a particular application is normally stated in related standard. For example, for helmet testing, most standard quote a velocity range between to 6-12 m/s (BS 6658: 1985, MS 1:1996, and FMVSS 218). Therefore, some of Macaulay's (1985) data is presented in this article as a general guideline for drop weight testing machines.

Features of Basic Mechanical Components

The basic mechanical requirements are presented in the following paragraphs. It is to be emphasized here that this article is not considered as a detailed design reference, but a basic guideline as some details will depend upon the exact application intended which is helmet testing that may not be suitable for other applications.

Propulsion and Guidance

Two essentials for the success of impact tests are means of bringing a moving mass up to speed and a means of ensuring that the impact occurs at the right location and in the correct orientation. In general, accurate guidance is more important than accurate speed, because its easier to make allowances for speed variation in a test which is otherwise correct than to compensate, for instance, for an event occurring partly out of the field of view of a camera. Some typical types of propulsion are shown in *Fig. 1.* As shown, at low speeds, modified static test apparatus may be used. Gravity drop weight test

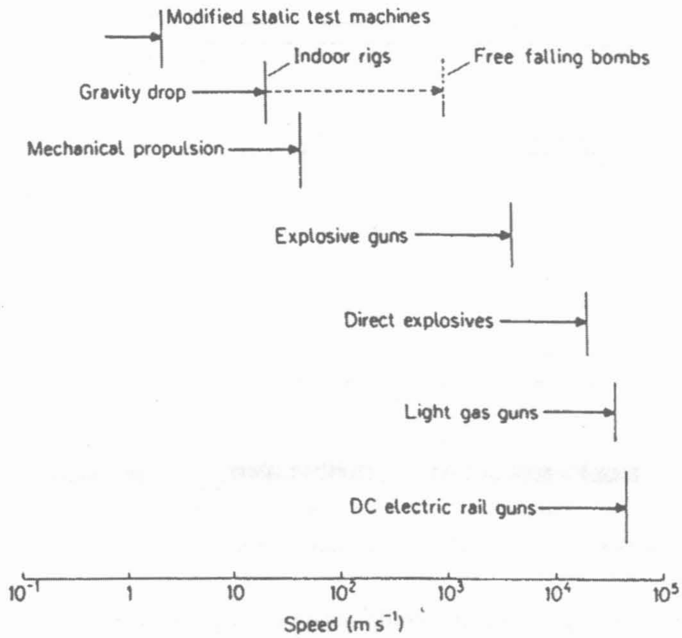


Fig. 1: Types of propulsion (Macaulay 1985)

rigs provide a simple and repeatable means of propulsion at speeds of up to about 25 m/s (Macaulay 1985).

With small specimens used to test material properties, guidance is usually maintained throughout the test. Otherwise guidance might be removed once the moving mass is up to speed. Guidance can be achieved in various ways such as wire ropes with non-steel bushings, hardened steel, and/or stainless steel rods with rolling bearings, or structural steel with pulleys mounted on bearings (Hamouda and Hashmi 1998; Broutman and Rottem 1975 and Colakoglu and Yildirius 1993). It is to be emphasized at this stage that any guidance shall have minimum friction forces acting on the drop mass.

Frame Layout

One of the interesting issues which face the designer is that various configurations are possible for the frame skeleton of the rig. So, what is the most suitable frame layout? This might lead to another question, which is, what the existing designs look like and what their positive and negative features are. In other words, what can we learn from the available data on drop weight rigs, which is scattered on the low velocity impact subject publications. Of course, none gave complete details of their design, but by collecting bits and pieces from different sources, reasonable figures can be combined, which together with basic structural mechanics knowledge, could be used to assist in design rules development. *Fig. 2* shows sketches of few layouts, which could be utilized. The difference between *Figs. 2 a* and *b*, is the position of the columns, whether on top of the foundation or directly on to the ground floor. The choice will depend on the size of the machine and the degree of flexibility required (possibility of repositioning or removing the foundation).

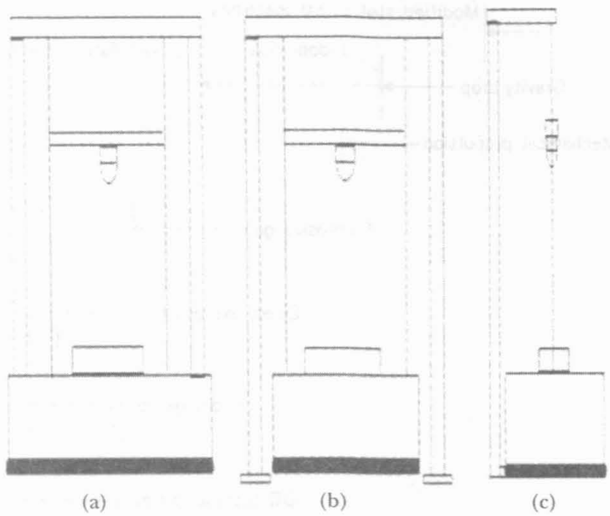


Fig. 2: (a) Columns on foundation, (b) Columns on ground floor, (c) Columns on the back

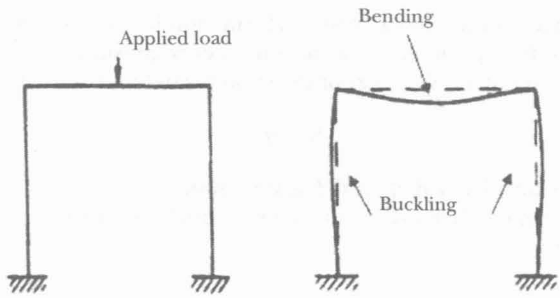
Both layouts in *Figs. 2 a* and *b* could have two in plane or four columns as a box frame depending on the intended application and rigidity requirements. However, *Fig. 2 c*, which shows two columns at the back layout, is the least rigid and could be used for small to medium applications (large weight would create large bending stress on the guides and consequently high friction forces).

Foundation

The type and size of foundation depends upon the application requirement, particularly the impacting mass and speed. In general, the main criterion is the mass of the foundation. The materials could be steel or strongly reinforced concrete to withstand impact loads. The other criterion that needs to be considered is the damping capability of the rig which can be almost fulfilled by providing a thick mat of rubber or similar material at the bottom of the foundation. This layer would absorb the shock and prevent any reflected stress waves from interference with the test results. Regarding the main criterion which is the foundation mass, certain application standards which use drop weight machines such as helmet testing standards generally specify the minimum foundation mass required (BS 6658: 1985, MS 1:1996 and FMVSS 218).

Structural Design Checks

In order to have confidence on the frame strength, some structural checks are necessary. First, the design load is determined based on the intended application. Then, the free body diagram can be drawn and the forces on each member determined and analysed. The shear force and bending moment diagrams are then drawn for each link. Cross sections are estimated based on simple mechanics theories for bending, deflection, and column buckling. The simplified procedures can be used and there is no need for complicated calculations, particularly for floor-mounted frames where the case could be considered as a completely static loading design. *Figs. 3 a* and *b* show an exaggerated sketch to provide better visualization of the anticipated deformation path. Such procedures are well documented in the literature (Ambrose 1997; Gero and Cown 1976; Brockenbrough and Merritt 1999).



a) Front view of frame loading
b) Expected deformation path

Fig. 3: Anticipated deformation shape for one view of the frame

Energy Consideration

In general a gravity drop weight consists of a steel base plate assembly, a ram that holds the striker, supporting columns, which guide the falling weight (ram and the striker) and a device to raise the ram and the striker to the desired height. The kinetic energy of the falling weight depends on its weight and the height of the fall (Colakoglu and Yildirius 1993).

The energy is mainly dissipated in the following ways:

- Deformation of the specimen
- Rebound of the striker assembly.
- Elastic deformation of the drop weight machine.

The first two ways are to a great extent dependent on the deformability of the materials constituting the specimen. The energy dissipated in deforming the specimen would be termed the crash energy E_c.

The energy of rebound depends upon the coefficient of restitution between the two surfaces. If m_1 and V_1 are the mass and the rebound velocity of the striker assembly respectively, the rebound energy E_r is given by:

$$E_r = \frac{1}{2} m_1 V_1^2 \tag{1}$$

Some of the energy is lost in the guidance due to opposing frictional forces (E_g). The machine frame absorbs a certain amount of energy due to vibration of different parts. This is because of the transfer of momentum from the striker. The test specimen will also absorb certain amounts of energy in the form of heat. Grouping all these losses under the heading of the transmitted energy E_t, total energy, E, created by dropping the striker can be expressed as:

$$E = E_c + E_r + E_g + E_t \tag{2}$$

However, this energy is equal to the initial potential energy of the striker assembly at its falling height h.

$$E = W_1 h = E_c + E_g + E_t \tag{3}$$

The test specimen undergoes a plastic deformation in a non-elastic collision between the striker and the test specimen. The ratio of energy consumed in deforming the test specimen to the total potential energy of the striker is defined as the blow efficiency (η_b).

$$E_c = \eta_b E \tag{4}$$

E_f can be directly calculated if η_b and E are known.

The blow efficiency, defined in the above equation can be calculated from the following equation:

$$\eta_b = \frac{1-e^2}{1+W_1+W_2} \tag{5}$$

where "e "is the coefficient of restitution and defined as

$$e = \frac{V_2 - V_1}{V_0} \tag{6}$$

and W_1 and W_2 are the weight of the striker assembly (falling weight) and the weight of the steel base plate assembly respectively. V_1 and V_2 are after impact velocities of the striker and the steel plate assembly respectively. V_0 is the initial impact velocity of the striker. In many cases, the rebound velocities V_1 and V_2 are small compared with the impact velocity of the striker V_0. Therefore, the factor "*e*" approaches zero. Then the blow efficiency becomes

$$\eta_b = \frac{1}{1+W_1/W_2} = \frac{W_2}{W_1+W_2} \tag{7}$$

When this ratio is determined for a particular design, then E_f can be calculated from Equations (1) and (7).

It could be observed that for a more efficient impact test the striker assembly mass should be minimized. This approach was considered in the drop weight designed in this research program by increasing the height to the maximum feasible (see next section).

- *The Impact Velocity*: The impact velocity is given by

$$V_0 = \sqrt{2ah} \tag{8}$$

where h is the height of the drop, "a" is the acceleration of the striker

- *Friction Effects*: If **R** is the frictional force and **P** is the constant vertical force (for gravity drop P = 0), then the acceleration of the striker is equal to

$$a = \frac{W_1 + P - R}{m_1} \tag{9}$$

where m_1 is the mass of the striker.

As mentioned previously for gravity drop weight tester, no external driving force is applied on the striker (i.e. P = 0), therefore equation (9) takes the form

$$a = g - \frac{R}{m_1} \tag{10}$$

It is clear that in gravity drop weight testers, the acceleration of the striker is slightly less than the gravitational acceleration ($a < g$), due to frictional losses. To have a maximum impact speed of the striker for a given height, the frictional force (R) has to be minimum.

DATA RETRIEVAL

The importance of properly selected data retrieval systems for drop weight testing machines need not be emphasized here. Much care should be taken in the selection process to obtain meaningful results.

Various data retrieval components in use for drop weight testing rigs are scattered in the literature, which are either identical or slightly different (Collombet *et al.* 1998; Volt *et al.* 1998; Zho 1998; Broutman and Rottem 1975; Winkel and Adams 1985; Gilchrist and Mills 1996; Gilchrist and Mills 1994). This part explores this subject and provides some useful guidelines in selecting drop weight data retrieval systems in general.

In this section data retrieval system means all equipment/ instrumentations used to retrieve and analyse data during an impact testing. This includes the following:

- Electronic instrumentations (Transducers)
- Image acquisition System (Photography equipment).
- Electronic data acquisition system.

Due to the wide range of applications of these instruments, only the essential practical issues to the drop weight impact testing machines have been considered here. Electronic measurements and data acquisition theories are well documented in related texts and periodicals (Coombs 1999).

Transducers (Sensors)

Transducers are the sensing elements, which are used to measure the impact response related parameters such as load, acceleration and velocity. The three transducers, which are selected for the drop weight impact testing machine under this study, are the *accelerometers, load cells,* and *photo* sensors. This selection has been made based on drop weight rigs instrumentation found in the literature for crashworthiness studies and considering helmet testing performance requirements (Broutman and Rottem 1975; Winkel and Adams 1985; Dias 1999; MS:1 1996).

In general, the main advantages of electronic transducers are the provision of continuous records in a form suitable for automatic processing. The disadvantages are that a separate channel is needed for each item recorded, and that transducers are easily damaged and they can modify the behaviour of the test specimen (Macaulay 1985). For both accelerometers and load cells the piezoelectric types are the best choice for shock resistance capability (Gilchrist and Mills 1996; Gilchrist and Mills 1994; Dias 1999; BS 6658: 1985; MS 1:1996; and FMVSS 218). Details on piezoelectric principles will not be covered here as such data can be found in relevant textbooks or recognized company product catalogues such as Kistler and Instron (Dias 1999; Kistler Product Catalogue 2001). For preliminary selections, a margin is needed for the expected highest acceleration or load, taking into consideration that a very large gap between the expected test values and the instrument range may increase the percentage of the ± error, particularly for the load cell. Photo sensors are adopted in drop weight testing rigs as means for measuring velocity between two vertical points or just before impact. Furthermore, they can be effectively utilized for data capture via external triggering connection in the data acquisition card. These sensors are specialized equipment and sold by few recognized companies. They can be of through beam type or reflective type. Generally the through beam is utilized for drop weight testing rigs (Gilchrist and Mills 1996; Gilchrist and Mills 1994; Dias 1999 and KEYENCE product Catalogue 2001).

Image Acquisition System (Photography)

Photographs record only the displacements but they can do this in great detail. All types of impact can be recorded and taking of photographs usually has no effect on the test itself. A major use of photographs is to allow impacts to be studied qualitatively at leisure and this can give considerable insights to pattern of behavior without further analysis (Macaulay 1985). Recently, photographic apparatus, particularly high-speed photography, is increasingly being used in drop weight testing machines.

Therefore, it was decided to include the photographic equipment as a main component for the drop weight-testing machine in this study.

Two methods which can perform this task are now in the market. The first is by using a stand-alone high-speed digital camera system, which is normally positioned on tripods at suitable locations as shown in *Fig. 4*, (EASTMAN KODAK COMPANY). The images and movie files can be transferred to the PC after the test is completed. Therefore, the storage capacity of the camera is an important factor to be considered. The second method is by using the computer-based image acquisition techniques where the digital camera is connected to a standard PC through image acquisition card (IMAQ). Then by using an image visualization and analysis software, such as IMAQ-VISION plug-in program to labVIEW developed by National Instruments, the impact test photography can be processed and analyzed. An example of such a system is shown schematically in *Fig. 5*. Also, *Fig. 6* shows a PC-based image acquisition system using Sony digital camera as an integral system assembled by National Instruments as a complete image acquisition package (National Instruments Catalogue 2001).

Analogue cameras can still be used as a stand alone or as PC-based image acquisition system but generally they have low frames per second capability (less than 35 fps). Therefore, for crashworthiness studies digital cameras have replaced the analogue cameras due to the superior performance such as the high frame rate, high spatial resolution, and high contrast.

In general, the most important parameter that has to be precisely specified for proper photographic performance is the frame rate per second for the digital camera.

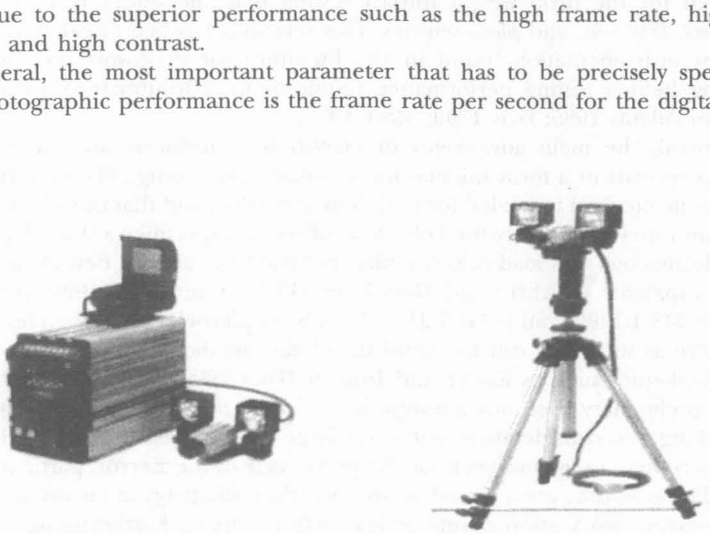


Fig. 4: Stand alone high speed digital camera system (EASTMAN KODAK COMPANY)

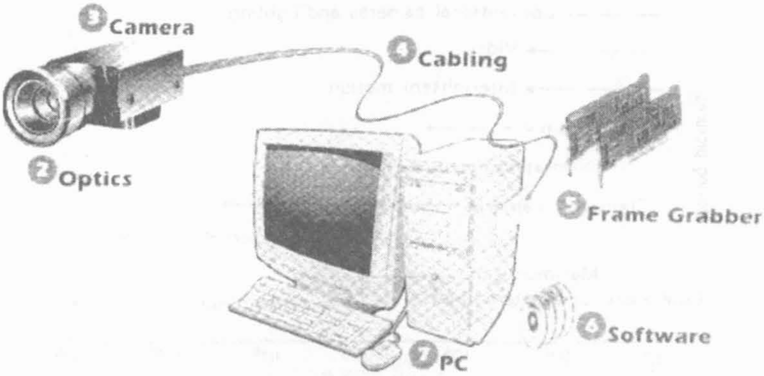


Fig. 5: Typical PC-based image acquisition system (National Instruments Catalogue 2001)

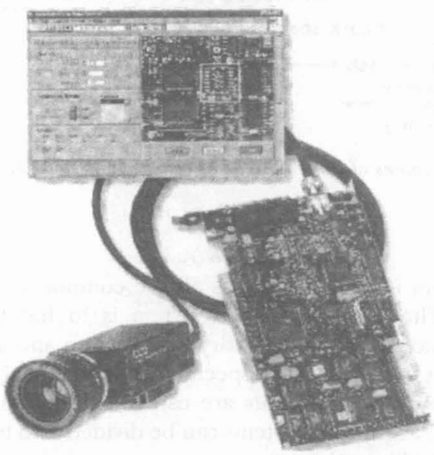


Fig. 6: An integrated image acquisition system (National Instruments Catalogue 2001)

The range of frame per second for various photographic equipment is shown in *Fig.* 7 (Macaulay 1985). The quality of the picture increases as the framing time increases, but the cost also increases sharply. Though the figure may not be recent, it still gives an idea about the significance of the framing parameter.

Therefore, it is clear that the experience is essential in deciding on the frames per second (fps) required for certain applications, as any mistake may lead to redundant cost. Broutman and Rottem (1975) used 6000 frames per second for drop weight testing machines to study the impact strength of fibre composite materials. Therefore, this value can be considered as suitable with a minimum of about 1000 fps. For better visualization performance on high speed impacts the frames per second can be increased up to 10,000.

Finally, it is worth mentioning here that the need for high speed camera system for a particular application must be carefully evaluated, as in certain circumstances it may not be necessary or it does not provide vital information to justify the high capital cost.

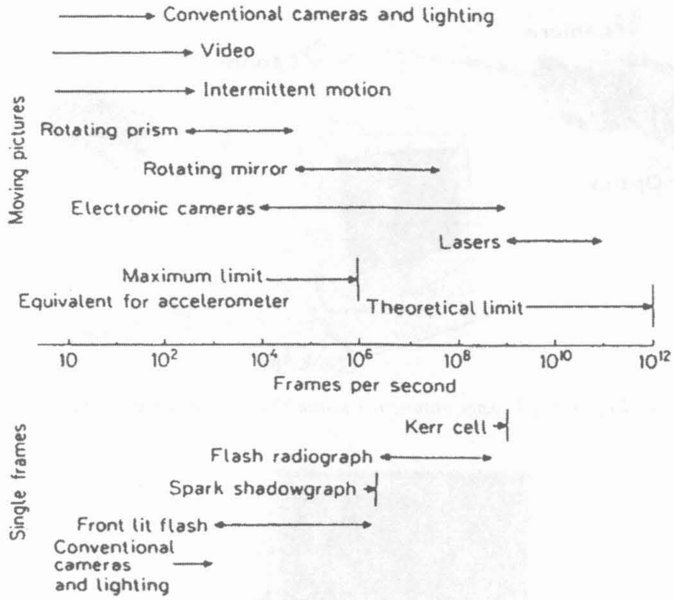


Fig. 7: Comparisons of camera speeds in frames per second (Macaulay 1985)

Data Acquisition Systems

A data acquisition system is defined here as all the components behind the sensors in the measuring loop. The function of this system is to handle the signal, perform filtration and tuning, and make the necessary visualization and analysis. The system can be designed in different ways to achieve specific requirements. For drop weight impact-testing machines, the number of sensors are usually limited and specified. Therefore, the most applicable data acquisition systems can be divided into two methods/categories:

- Method A: Using Oscilloscope.
- Method B: Computer-based data acquisition systems (Virtual Instruments).

Both methods include signal-conditioning components either as built-in or separately connected. The signal conditioning components are usually filters and amplifiers. These units are required to tune and filter out the unwanted noise and consequently allow for meaningful visualization of results. Filters and amplifier signal conditioning sometimes comes in a single unit, which includes both functions in a multipurpose unit or can be purchased individually. Certain parameters need to be known in selecting the suitable units including sensor output voltage.

However, as a useful hint, quite often well-known vendors will assist the purchaser in selecting the most suitable unit if sufficient details about the whole system, particularly the sensors are provided. Data acquisition systems are described in the following paragraphs.

• *Method A (Using Oscilloscope)*

For this method, the features of the oscilloscope are the governing factor of the output data quality, as more sophisticated digital oscilloscopes are now available in the market. These can handle large amounts of data and can have large numbers of channels, and signals can be tuned very accurately. Also the results can be printed or stored in a floppy diskette or other hard drives, which can be transferred to a standard program like Excel. However, oscilloscopes, which are suitable for impact testing with sufficient features are generally expensive and have no means for upgrading. The degree of flexibility is limited with the available features and no modification/ programming can be made to the output results. *Fig. 8* shows a typical digital oscilloscope.

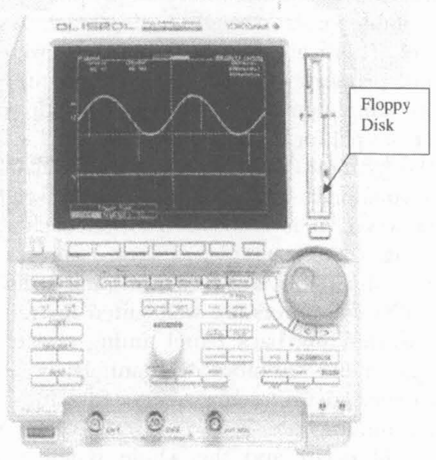


Fig. 8: Digital oscilloscope with enhanced features such as floppy diskette storage facility (FD) and external trigging (Yokogawa product catalogue 2001)

• *Method B (Computer-based data acquisition systems)*

This method is termed computer-based data acquisition system, which basically consists of the components shown in *Fig.9* (excluding the transducers). Generally, in this technique, the sensor analogue signal (Low voltage electric signal) is conditioned first, then converted to digital signal through A/D cards (boards). Then, the application software will be used to visualize and analyse the results (Stahlin 1999; Corcon 1999; Stahlin and Christ 1999; Kwock 1999; National Instruments Catalogue 2001).

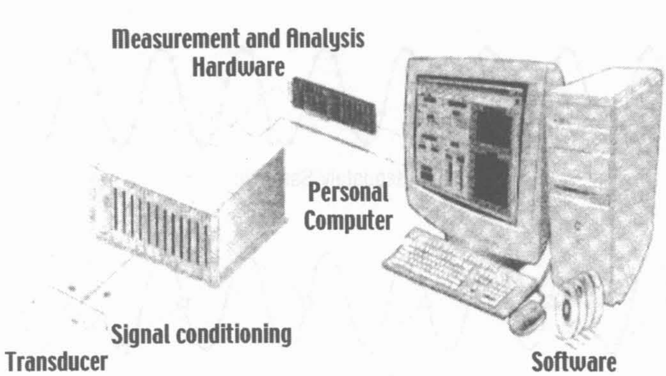


Fig. 9: Simple PC-based data acquisition system (National Instruments Catalogue 2001)

After A/D conversion, an application program is generally required for visualizing and analysing the results. These two components are described separately in the next paragraphs.

The A/D Conversion Card: This is the most critical part of the data acquisition system, which needs to be carefully selected. It can be considered the heart of the system. A/D cards can be for analogue I/O, digital I/O, or for timers and counters. Also, some cards are designed as multifunction cards where all previous tasks could be performed. The latter are the most suitable for drop weight-testing machines as they have more than one type of data channel. There are several parameters, which have to be specified before an A/D card can be properly selected. Among those are: the type of PC platform used, number of channels, sampling rate, analogue bandwidth, resolution, and triggering mode. A/D boards for various platforms such as Desktop (PCI & ISA), Laptop (PCMCIA), Industrial PC (PXI), or Workstation (VXI) are now widely available. Therefore, according to the type of computer (platform) allocated to the drop weight machine, the proper card will be selected. However, it is to be noted that each type of platform has its advantages and disadvantages. For example, desktop is inexpensive, readily available, and the latest technology is obtainable, but rack mounting is difficult and few expansion slots are available, while PXI computers are well suited for rack mounting, have more slots, the same software as desktop, back panel timing and triggering, but it is more expensive. The second parameter (number of channels) is selected according to the number of instruments expected with some reserve for future expansion. The third parameter, which is the sampling rate, is also critical. If it is not specified properly a liasing of the results would occur and the whole system result will be useless or misleading. *Fig. 10* shows this effect more clearly. Therefore, it is very essential to correctly estimate the number of samples, which can represent the required output in the test time domain. This requires some experience on the estimated duration mechanism of the impact events under consideration. However, theoretical equations can be obtained in data acquisition references, which would assist in this estimation (Corcon 1999; Vilbiss 1999; National Instruments Catalogue 2001).

The analogue bandwidth is also an essential parameter, which can be overlooked in the selection process or may not be provided by the A/D card vendors. In general, analogue bandwidth describes the frequency range (in hertz) in which a signal can be accurately digitised. This limitation is determined by the frequency of the input path. Input signals with frequencies above this bandwidth will result in loss of amplitude and

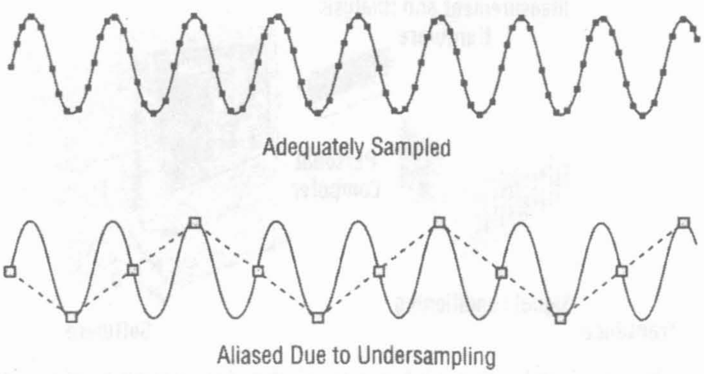


Fig. 10: Effects of sampling rate on the output signal (National Instruments Catalogue 2001)

phase information. The effect of this parameter is shown in *Fig. 11*. The most efficient way to overcome such a problem is by specifying the sensor data clearly to the A/D card vendor who in turn will advice if there are any restrictions. In *Fig. 11*, the output signal is only up to the card limit (National Instruments Catalogue 2001)

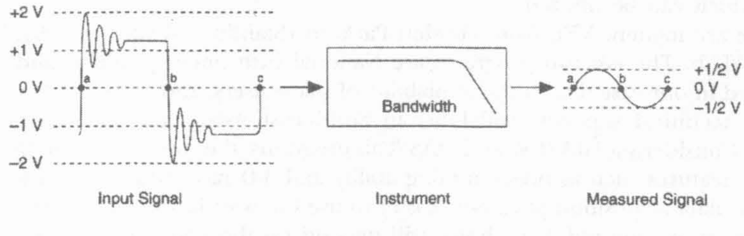


Fig. 11: Effect of bandwidth on the measured signal (National Instruments Catalogue 2001)

The last parameter is the triggering mode. In general, triggering means the process of determining the exact instant in time to begin the signal capture. This item is, in fact, a challenging parameter and could be considered as a main factor in comparing different A/D cards in the purchasing stage. A/D cards have various triggering provisions and these generally determine their final price. *Fig. 12*, shows one of the sophisticated A/D cards, which has various triggering modes. The specification of the card is usually defined if the triggering mode is analogue (external), digital (internal) or software control. The software control mode of triggering is usually done through the data acquisition software. This mode of triggering is often limited mainly by the computer type and speed. However, an A/D card which has an external triggering provision is usually more expensive, but it is quite beneficial for drop weight testing machines.

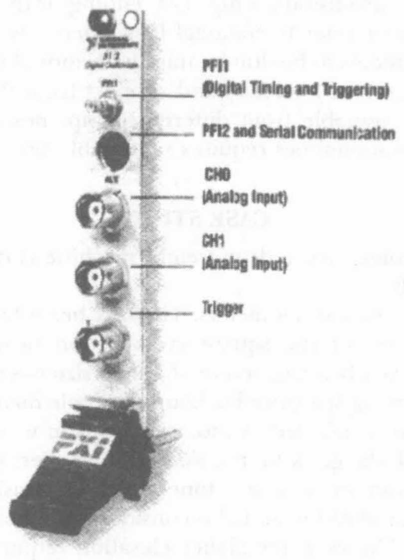


Fig. 12: Front view of typical computer-based data acquisition board with external triggering (National Instruments Catalogue 2001)

The Application Software: The application software function is to visualize and analyse the data acquired. This can be achieved by different ways. For researchers who have no time and knowledge on advanced programming languages such as C++ or Visual Basic, using any of the available graphically-oriented data acquisition and analysis software is recommended. Three competitive data acquisition programs are most suitable in the market which can be utilized.

These are namely: VEE from Hewlett Packard (Stahlin and Christ 1999), labVIEW, and DASYLab. The last two programs are National Instrument products and would be considered in our case due to the availability of many users, and Notational Instruments company technical support availability in South-east Asian countries, particularly in Malaysia. Considering labVIEW and DASYLab programs, the former is more flexible and has more features such as programming ability and 3-D plots while the latter is meant mainly for data acquisition purposes, easier to use but with less flexibility, particularly if programming is required The choice will depend on the applications complexity and extent of the testing required. However, if the requirement is only for simple data acquisition and the data acquisition components are within the available DASYLab Blocks/ Modules, then it may be the best choice. Otherwise, labVIEW would be more appropriate, particularly if the future application will require more facilities such as image acquisition system or similar application. The important point, which needs to be considered, is that the type of A/D card must be supported by the selected program. Also, some recognized companies, such as DEWETRON, usually develop their own data acquisition programs to work with their cards. Such programs usually have limited capability and the use is limited to that particular brand. However, it is noted that such companies generally produce cards which work well with advanced programs such as labVIEW or DASYlab, but this usually needs to be clearly mentioned in the A/D card specification before purchasing.

Recently, National Instruments developed a family of data acquisition programs with different capabilities and labVIEW is one of them. These programs vary in features and their selection will depend upon the application, their complexity starting from simple non-programmable data acquisition only and ending with programming and data acquisition. The reader may refer to National Instruments' web site for further details. It is noted that labVIEW seems to be dominating the National Instrument market, which might be due to the degree of flexibility and support from the company.

Other programs are available from different companies which have intermediate complexity and their use sometimes requires reasonable programming skills.

CASE STUDY

Based on the previous guidelines, a drop weight machine is designed and constructed with the following details:

The overall height of the rig is 4 meters. The box beam frame has been selected as frame layout with the size of the square cross-section beam equal to 5 inches, a supporting intermediate box beam structure of 4 inch size has been installed at 2 meters height to provide more strength against buckling. A simple manual wire rope and pulley-lifting mechanism has been installed. A motorized system would be installed at a later date. A heavy-duty steel flange with recession for washer type load cell has been fabricated. The foundation mass is one tone which is considered sufficient for the helmet-testing intended application and also considered suitable for similar applications such as material testing. However, for higher elevation requirements or heavier loads, the foundation could be removed and the steel flange could be anchored directly to the floor. Therefore, the impact could be sustained by the more rigid reinforced concrete floor or possibly different design foundation replacement. A 25 mm rubber matt has been introduced between the floor and the foundation for initial and reflected shock wave absorption. A one-inch normal steel bar with guided rubber pulleys mounted on friction-less ball bearing has been provided. *Fig. 13* shows the front views of the drop weight that has been constructed. In fact, this pulley system will have some frictional effects on the striker velocity, but as it is intended to measure the velocity with photocell just before the impact, minor losses could be neglected.

The details of the selected data retrieval system are presented in Table 1. Due to cost constraint, high-speed camera with 10, 00 fps is under bidding and not yet purchased.

TABLE 1
Selected data retrieval components

Item	Instrument Details	Specification	Brand
Sensors	Load Cell washer Type	100kN washer type, 9102A	Kistler
	Shock accelerometer	Pezotron low impedance, 8742A	Kistler
	Photoelectric Sensors	Two Thru- beam Type	KEYENCE Sensors
A/D Cards (Two brands for reserve and flexibility)	i) -Low–Cost Multi-function Card	- PCI- 6023E 200 ks/s	National Instruments
	ii) -Multi-function card	-ICT-DAS, No: PCI 1800 H-nda 330 ks/s	SDC
Application Software	LabVIEW	Full development System for Windows 2000/ NT/Me/9x, Version 6	National Instruments

CONCLUSION

From the previous drop weight analysis and conceptual design, we can conclude the following points:

- For crashworthiness studies, particularly those dealing with prototype testing, it is better to have an in-house fabricated drop weight machine which is built according to the required degree of flexibility, work space and rigidity rather than purchasing an expensive limited workspace drop testing rig.
- The ground fixed box frame layout is the most suitable, from the rigidity and stability point of view, but is less flexible.
- For more efficient impact the mass of the striker should be minimized and other parameters such as the height could be increased to achieve the same impact energy.
- A simple economical guiding system could be designed if the velocity could be measured just before impact by other means, such as photocells.
- The selection of transducers depends on the exact application. However, pezo-electric accelerometers and load cells are the choice for drop weight machines.
- Photography is becoming essential for drop weight machines. Either a stand alone of PC-based systems could be utilized.
- Data acquisition could be achieved using digital Oscilloscope or PC-based data acquisition system where A/D board is utilized with application software.

Therefore, this article has provided some useful criteria and worked example for drop weight testing machine that is suitable for crashworthiness studies. However, some minor points could not be completely covered in this article to avoid unnecessary complications.

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