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NEW DESIGN FOR DYNAMIC PRESSURE CALIBRATION SYSTEM

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ABSTRACT

Dynamic pressure sensors calibration and their traceability is a new metrology field. Since such dynamic measurements are essential in the design and development of modern engines, and many industrial applications. It is necessary to establish national Egyptian standard for dynamic pressure measurements which can provide traceability to the industry. This paper presents a new design for dynamic pressure calibration machine. The main idea of this machine depends on generating an impulse pressure signal applied to both the sensors under calibration and a reference sensor. The machine is fully automated using LabVIEW software; the machine linearity and the repeatability are tested.

Keywords: dynamic calibration, hydraulic impulse, piezoelectric pressure sensor.

INTRODUCTION

Dynamic pressure measurements is a new metrology field and become a requirement in many applications such as automotive developments of combustion engines[1], new fuel injection system needs rapid changes of high pressure [2], ballistic pressure measurements[2,3], gas turbine and human blood pressure.

Based on the role of the National Institute of Standard (NIS) - Egypt in maintains, develop and establish of its own primary standard. Few national metrology institutes studied the calibration of dynamic pressure sensors such as Physikalisch-Technische Bundesanstalt (PTB), Germany. In their setup, a drop ball device drops a ball on a piston generates pressure pulse[5]. They used the change of refractive index with pressure to link dynamic to static pressure measurements. Two different transmitting medium were studied using the numerical method. National Metrology Institute of Turkey (UME), characterizes pressure transducer using two different methods for dynamic pressure measurements[6], the first method manually drop mass system and the second using material impact test machine. The output of the two different methods was graphically compared. The comparison shows differences between the two systems output voltage values at each pressure point for both manual drop mass method and the corresponding method. The least square method and liquid step wave generator stated [7]was used to calibrate three different pressure sensors. The transient method used depends on a same liquid steep wave is received by both reference pressure sensor and the test sensor. The method was suitable for calibrating pressure sensor frequency reaches 10 kHz. The mathematical modeling support new primary standard was presented in [8]. The study addresses two different approaches to realizing primary standards, one for the shock tube method and the other for a drop-weight method. The mathematical simulation was used to identify differences between the shock tube and drop-weight methods, to investigate sources of uncertainty.

The objective of the present investigation is to construct a dynamic calibration machine.

Experimental setup

The principle of operation of the machine constructed during this study is to drop a stainless steel cylindrical mass, with known characteristics, from a specific height on the piston head. The cylindrical mass, drop weight, transmits its kinetic energy through the piston to the fluid inside the pressure cavity. The pressure cavity, which comprises the sensors and the piston - cylinder assembly, contains characterized pressure Transmitting Fluid (TF) as stated by [4-6].The drop weight and the piston move downward with the same velocity. The energy of the falling weight is transferred to the fluid as compression energy which causes the pressure to increase. After releasing the total energy, the maximum pressure is reached and the reverse motion of the piston and drop weight takes place. They are pushed upwards with the same velocity until the piston is stopped and the falling weight rebounds.

Figure-1. Experimental setup of dynamic calibration machine.

The setup of dynamic pressure calibration machine is shown in Figure-1 and Figure-2. It consists of the main frame, pressure test rig, and measurements facility.

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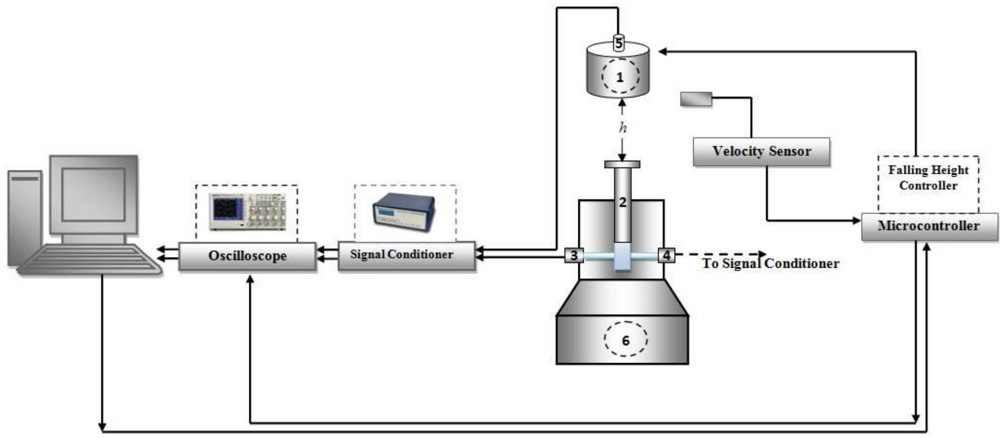

Figure-2. Layout for dynamic calibration machine: 1. falling mass, 2. Piston-cylinder, 3. Pressure cavity, 4.Referance pressure sensor, 5. Unit under test pressure sensor.

Mainframe, in Figure-3, shows a 3D drawing of the mainframe. The different parts of the main frame are listed in Table-1. The main frame of the dynamic calibration machine is designed rigid enough to withstand the specified maximum impact force. The mechanical structure of machine consists of:

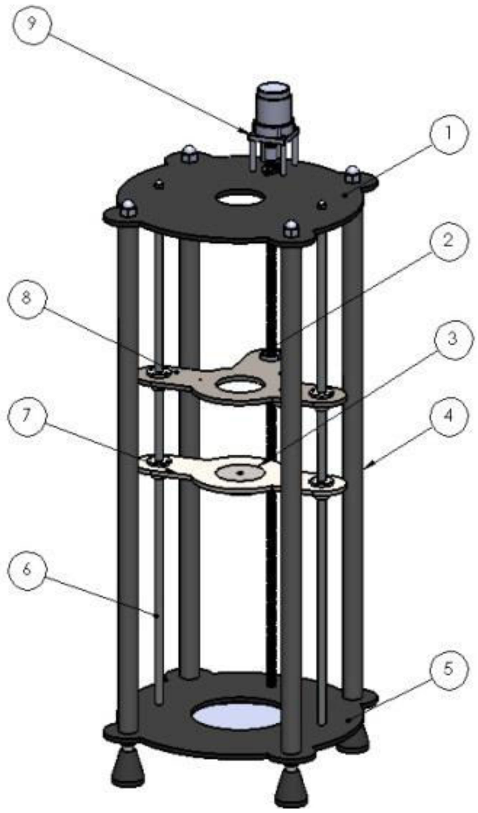

Figure-3. Mechanical structure of dynamic calibration machine.

Table-1. List of main parts.

No.	Part	QTY
1	Upper plate	1
2	Ball screw	1
3	Falling mass	1
4	Frame rod	4
5	Lower plate	1
6	Guide rod	2
7	Mass holder	1
8	Mass lifter	1
9	Stepper Motor	1

Mass lifter, vertically elevated by using ball screw, nut and driven by a 2-phase stepper motor. The mass lifter guided by two linear bearing and slide on two steel hard chrome rods. The mass holder is used as support for the falling weight. It consists of two linear bearing manufactured from Polytetrafluoroethylene (PTFE) material. It is sliding on two steel hard chrome rods. The mass holder lifted by the two electromagnets fixed on the mass lifter and controlled with Arduino Microcontroller through the developed program. Pressure test rig is shown in Figure-4. It includes piston 1, cylinder 2, pressure cavity 3, two pressure adaptors 4, and two dynamic pressure sensors 5, 6. One is the reference sensor and the second is the sensor under calibration.

Figure-4. Expanded view for dynamic pressure test rig.

Measurements facility

The Measurements facility includes an instrument for acquiring the out signal from the pressure sensors and signal conditioner. The output signals processing is executed offline under Matlab package platform. Two dynamic pressure sensors manufactured by PCB Piezotronics. Piezoelectric pressure sensor type is electrical charge output. It has a sensitivity of (0.25 pC/psi) and maximum pressure (15000 psi). The second sensor under calibration is model piezoelectric charge output with maximum pressure (80000 psi). The PCB shock accelerometer with sensitivity of (0.593mV/g) is a thread mounted onto the top of the drop weight. The signal conditioner is a charge amplifier with four-channel, with Incremental gain, x0.1 – x200 (step of 0.1). A digital storage oscilloscope, with 4 channels, sample rate on each channel up to 2 G sample per second (GS/s).

Measurement procedure

Measurement procurers consist of the following steps; (a) initial system adjustments and (b) calibration sequence.

A. Initial system adjustments

In the initial system adjustments, the following steps are done before start calibration sequence. The falling masses, mass holder, and piston are calibrated using the comparison method according to OIML R111[10]. It employs reference masses, shown in Figure-5, and digital electronic comparator balance, shown in Figure-6, at NIS, Mass Lab.


Figure-5. Falling masses.

Determination of the volume of the pressure cavity is carried out by weighing the empty pressure test rig using comparison method depends on OIML R111 [10], the Mettler Toledo electronic digital balance of resolution (0.001g) and reference masses of accuracy class E2 is used to determine the mass of empty pressure test rig. Figure-6 shows the equipment used in volume calibration.

Figure-6. Calibration volume of equipment.

The Di-2-Ethylhexyl Sebacate oil [11] with properties shown in the Table-2 fills the volume of pressure test rig using calibrated graded glassware.

Table-2. Di-2-Ethylhexyl Sebacate properties.

Density (ρ)	**913.9 kg.m-3**
Viscosity (η)	21.00 mPa.s
Bulks modulus (K)	1.65 GPa

The pressure test rig cavity which is filled with oil is weighed by the same method; the difference between the two masses is the net mass of the oil. The volume is determined using the following equation:

$$v = \frac{m}{\rho} \tag{1}$$

Where,m is the masses difference and ρ is the density of sebacate oil at reference temperature. The calculated volume is compared to the volume of calibrated gradedglassware, as a check.

B. Calibration sequence

The dynamic calibration machine is fully automated using a developed program. To make complete calibration sequence in such machine the following steps has to be employed. The major steps are mounting the UUT and RS sensors into the pressure test rig using suitable torque. The second is to remove air from the pressure cavity, install the piston-cylinder assembly. Run the LabVIEW program and set the target value. Finally, record the output signal.

RESULTS AND DISCUSSIONS

The dynamic calibration machine is tested to calibrate the piezoelectric pressure sensor. The range of applied pressure is from 20 MPa up to 70 MPa. The calibrated reference pressure sensor is used throughout the calibration procedures. Figure-7 shows the pressure output

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of the reference sensor at different heights. The vertical axis is the pressure amplitude in psi unit and the horizontal axis is the duration time in second, the pressure signal is considered by duration time about 5 ms with pressure amplitude various from about 20 MPa to 55 MPa.

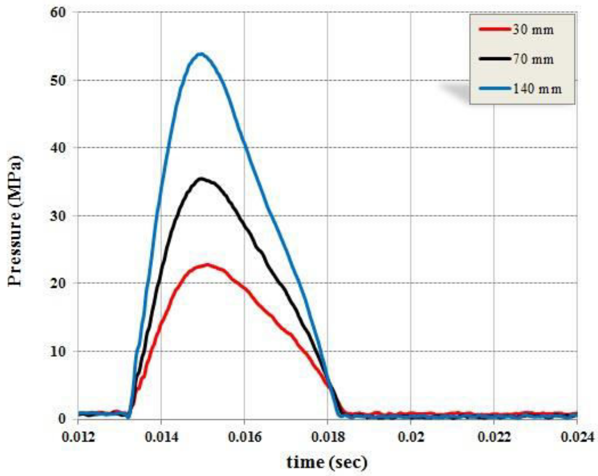

Figure-7. Generated pressure versus time for different falling heights.

The linearity of the calibration machine is tested as shown in Figure-8 using the reference pressure sensor. The maximum pressure amplitude at different heights is plotted and shows good linearity.

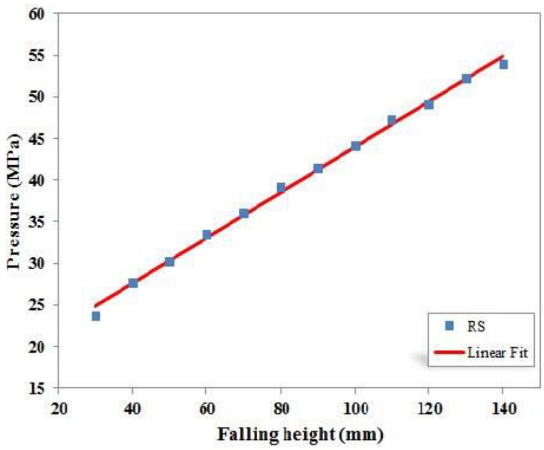

Figure-8. Linearity of calibration machine.

The quality of the measurements is tested using the repeatability test. The test is performed for three times of measurement at 13 cm height as shown in Figure-9. The relative standard uncertainty of the machine is equal to 1 %.

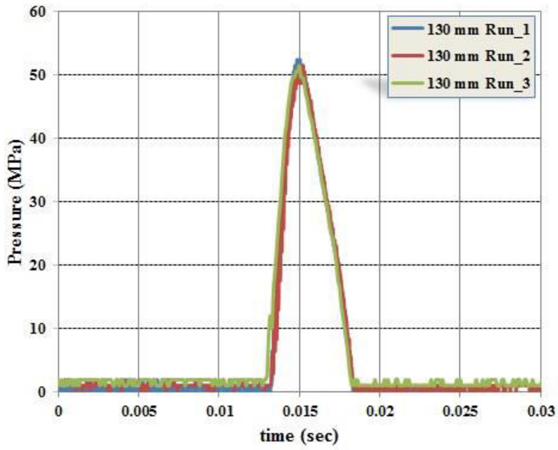

Figure-9. Machine repeatability.

CONCLUSIONS

In this paper, a new dynamic pressure calibration machine is designed. The machine is fully automated using the developed software. The main parameter is characterized at NIS; the machine linearity is tested and shows good linearity with a residual error of less than 1%. The machine repeatability is studied; the relative standard uncertainty 1% is obtained.

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