ESTABLISHMENT AND CHARACTERIZATION OF REFERENCE SYSTEM FOR CALIBRATION OF DYNAMIC PRESSURE SENSORS

By

Shaker Abdelwahab Shaker Gelany

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
MECHANICAL DESIGN AND PRODUCTION ENGINEERING

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Title of Thesis:

Establishment and characterization of reference system for calibration of dynamic pressure sensors

Key Words: Dynamic pressure, Falling mass, Dynamic calibration, Impulse generator

Summary:

Measurement standards for dynamic pressure and its traceability to the International System of Units (SI) is a novel field in metrology. Therefore, such standards are not commonly found in National Metrology Institutes (NMIs) that could enable calibration of modern dynamic pressure transducers. For several industrial fields using dynamic pressure technologies, this, in turn, limits quality assurance. Due to, the lack of traceability in the dynamic pressure measurements, the dynamic pressure sensors and transducers are calibrated using static or quasi-static methods. This may lead to significant errors in measurements as the behavior of the sensor in the dynamic mode differs from the static mode. In response to this problem, this study has been dedicated to establish and investigate a primary standard system for dynamic pressure measurements up to 100 MPa with relative uncertainty as low as 1.5 %. This new reference dynamic pressure standard is of crucial importance to develop calibration methods for dynamic pressure transducers. Furthermore, it provides the metrological basis for the dynamic pressure technologies such as automotive industries, military, aerodynamics, medicine, and material testing.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

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Nomenclature

p	Pressure, Pa
$p(t)$	Pressure function of time, Pa
h	Height of the liquid column, m
p_r	Reference pressure, Pa
g	Gravitational acceleration, m/s^2
m	Mass, kg
A_p	Effective area, m^2
M_1	Mach number of the shock wave
f_c	Cutoff frequency, Hz
f_H	Cutoff high-frequency, Hz
f_L	Cutoff low frequency, Hz
m_{tot}	The total mass of piston, drop weight and fluid mass, kg
$\ddot{x}_{max}$	The maximum acceleration, ms^{-2}
P_S	Pressure reservoir, Pa
W_{net}	work done, J
F	Force, N
x_{max}	Maximum piston displacement, m
m_f	Falling mass, kg
m_p	Piston mass, kg
v_0	Initial velocity, m/s
v	The resultant velocity, m/s
$V(t)$	Piston velocity, m/s
k	Stiffness, N.m
c	Viscous damping coefficient, N.s/m
K	Dynamic sensitivity, pC/MPa

n	Number of observations
$\bar{x}$	Mean of observations
N	Number of components
d	The width of the edge, m
t	The traveled time, sec

Greek nomenclature

α_1	The speed of sound in shock tube, m/s
γ_1	The gas specific heat ratio in shock tube
Δp	The pressure difference between the two chambers, Pa
ω_d	Damped frequency, rad/s
ω_n	Natural frequency, rad/s
ξ	Damping ratio
ρ_f	Fluid density, kgm^{-3}
ρ_a	the air density, kgm^{-3}
ρ_m	The mass density, kgm^{-3}
γ	The surface tension of the test piston oil, N
C	The circumference of the test piston, m
α_p	The thermal expansion coefficients of the piston material, $^oC^{-1}$
α_c	The thermal expansion coefficients of the cylinder material, $^oC^{-1}$
σ	The standard deviation

Abbreviations

SI	International System of units
NMIs	National Metrology Institutes
FEM	Finite Element Method
NIS	National Institute of Standards, Egypt
FFT	Fast Fourier Transform
DFT	Discrete Fourier Transform
PTB	Physikalisch-Technische Bundesanstalt, Germany
VTT	Technical Research Centre, Finland
MIKES	Centre for Metrology, Finland
NPL	National Physical Laboratory, UK
KRISS	Korea Research Institute of Standards and Science
UME	National Metrology Institute, Turkey
PTFE	Polytetrafluoroethylene
GUM	Guide of Uncertainty in Measurement
MC	Mount Carlo
PDF	Probability Density Functions
DAQ	Data Acquisition system
RS	Reference Sensor
UC	Under Calibration