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DEVELOPMENT OF A NEW PIEZOELECTRIC DYNAMIC PRESSURE GENERATOR FOR HIGH PRESSURE PERIODIC AND APERIODIC CALIBRATION

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Abstract – The need for dynamic pressure calibration has been increasing in the past years. Many solutions have been developed to satisfy this demand; nevertheless both present periodic and aperiodic systems do not cover the whole range of needs, calling for further development effort. In this contribution is presented a newly designed piezoelectric-actuated dynamic high-pressure calibration system that operates both periodically, 70×10^5 Pa peak-to-peak at 300 Hz, and aperiodically, almost 50×10^8 Pa/s.

Concept, design and first experimental results are described. First encouraging results foster further enhancement of performances.

Keywords: Dynamic pressure calibrator, piezoelectric, high pressure.

1. INTRODUCTION

The need for dynamic calibration of pressure sensors has been stated clearly since several decades [1]; on the other hand, the availability of test systems to cover these requirements is still lacking. Though in more recent years the topic has been brought back to actuality [2] and new development efforts have indeed bettered the reality both for aperiodic systems [3-6] and periodic systems [7-8], this still does not cover all the experimental needs.

The goal of the research and development work undertaken at the Microsystems and Electronic Research Laboratory of the European Aeronautic Defence and Space Company (EADS) presented in this paper has been to develop a flexible test instrument for comparative study of pressure sensors dynamic properties. An instrument that, through a piezoelectric actuation force, is able to deliver periodic, aperiodic and user-defined pressure profiles with a dynamic range of 70×10^5 Pa and verified preload possibility up to 200×10^5 Pa.

2. CONCEPT

The working principle of the device is based on generating dynamic pressure from dynamic force, applied through a piezo-actuated high-power dynamic force delivery system, which has been previously developed in the neighbour Mechatronics and Dynamics Department.

The introduction of piezoelectric actuators for the generation of dynamic pressure goes back at least forty years [9], but was limited in the pressure range from actuators specifications. The technological development definitely changed the situation; the present work illustrates a system with a dynamic range at least 7 times greater as the last reported effort in this direction [1].

In the system the actuator force is applied through a stamp onto a steel membrane that seals a pressure chamber filled up with a low compressibility liquid, as shown in Fig. 1.

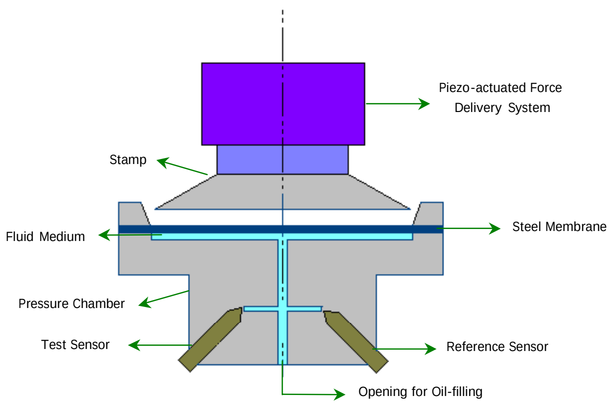

Fig. 1. Conceptual model of the system

The application of force results in the deflection of the steel membrane and a reduction of the liquid volume in the pressure chamber, leading to an increase of the pressure. The pressure hence developed is measured by reference pressure sensors connected to pressure ports on the chamber, in this way that calibration of the sensors under test is achieved.

3. DESIGN

Piezoelectric actuators are able to deliver great forces (up to 10^5 N), but they are only capable of very small displacements (in the range 100-200×10^{-6} m). To generate high pressures with the small volume displacements achievable with a piezoelectric actuator a considerable effort is needed in the design phase. Particular attention has been invested in the calculation of the membrane deflection, through standard analytical methods [10], and in the simulation of the system through Finite Element Modelling (FEM) with ANSYS 6.0. FEM is needed to model the contact between the membrane and the stamp. On the other hand, the Fluid Structure Interaction (FSI) problem, which determines the pressure change in the system generated by the membrane deformation, could not be modelled with FE due to its complexity. Therefore, a specific integrated method had to be developed in house to be able to perform the simulations needed for the design. The method proved to be highly efficient, as shown from the good coherence between simulation and experimental results in the design verification tests in Fig. 2.

The more recent version of the simulation program, ANSYS 7.0, should overcome the present modelling limitation for static and dynamic FSI, but this has not yet been demonstrated.

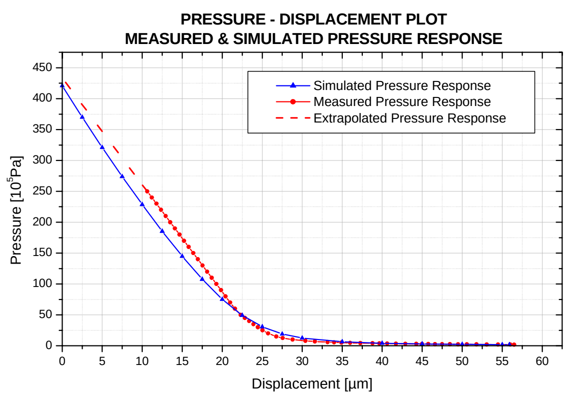

Fig. 2. Comparison between simulation and experimental results

Maximisation of the ratio between active volumes, which can be compressed through the deformation of the membrane, and dead volumes, resulting from adaptors and pressure distribution channels, is critical to obtain a wide dynamic pressure range. Thanks to the minimal fluid volumes (~ 2×10^{-6} m^3), no major safety measures needs to be taken although the high pressures that the system can reach. Moreover, during the chamber filling process, the absence of gas bubbles in the pressure transmitting fluid plays also an important role. The design is shown in Fig. 3.

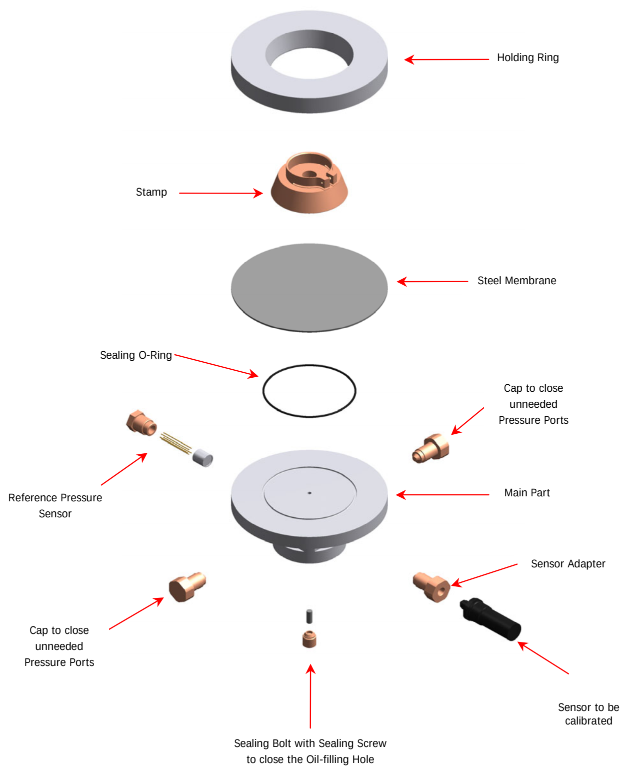

Fig. 3. Explosion view of the system

4. MANUFACTURING

In order to obtain the needed active volume for the high-pressure dynamic with small displacements produced by a piezo-actuator the membrane needs to have a rather wide surface, bringing the ratios between membrane diameter and membrane displacements over three order of magnitude. This sets high requirements of evenness and parallelism between pressure chamber, membrane and stamp. Moreover, to allow an adequately long system operating time between two fluid fillings, leakages have to be kept far below 10^{-9} m^3/60 s, calling for highly polished surfaces.

The mentioned constraints make the manufacturing a challenging precision mechanic effort.

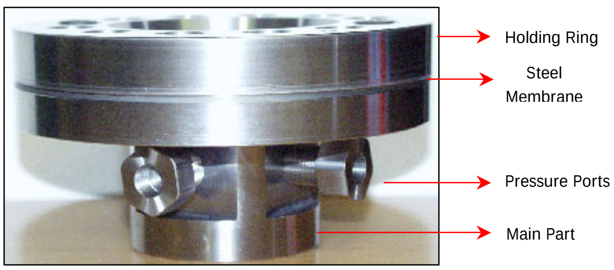

Fig. 4. Assembled pressure system

4. EXPERIMENTAL RESULTS

To determine its performances, the Dynamic Pressure System (DPS) has been clamped together with the piezo-actuator; the experimental set up is schematised in Fig. 5. Through a hydraulic system is possible generate to preloads on the DPS so that the dynamic characteristic could be investigated at different pressure ranges as shown in Fig. 6. Moreover, through laser interferometer measurements it has been possible to verify simulation results as presented in Fig. 2.

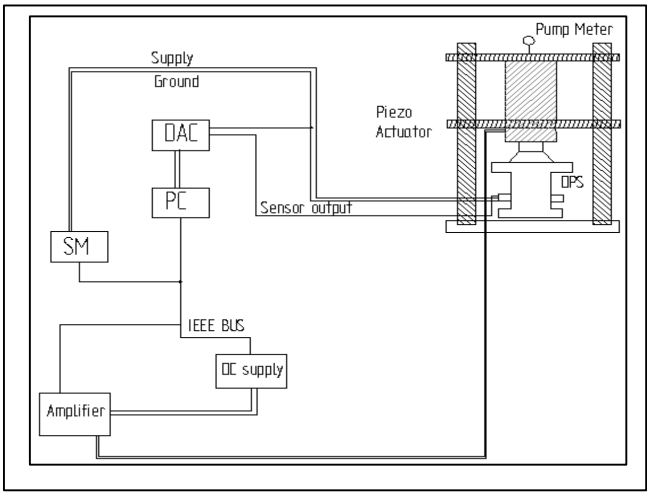

Fig. 5. Experimental set up

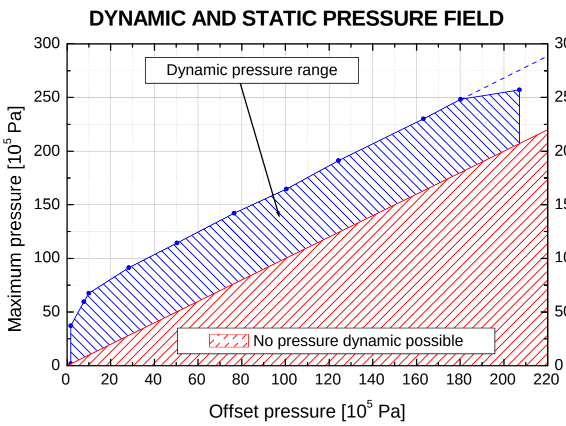

Fig. 6. Measured static and dynamic range of the system

Major system dynamic characteristics determined in the first experimental investigations have been gathered in table I; two significant results examples are given in Fig. 7 and 8.

TABLE I. System performances

	Periodic performances	Aperiodic performances
Dynamic range	70×10^5 Pa peak-to-peak	56×10^5 Pa 10 to 90%
Speed	300 Hz	46×10^8 Pa/s 10 to 90%
Phase shift [1]	$2{,}4\times10^{-4}$ s	$4{,}8\times10^{-4}$ s

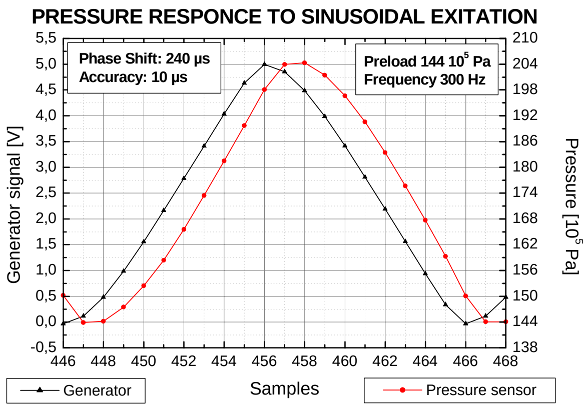

Fig. 7. Result of a periodic system operation test

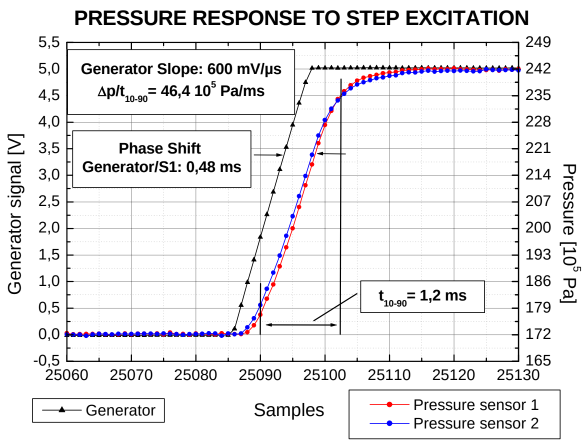

Fig. 8. Result of an aperiodic system operation test

[1] Phase shift between generator and sensor signal.

5. CONCLUSIONS

An innovative dynamic pressure calibration system has been presented, which offers possibilities for a whole range of calibration tasks. Furthermore, thanks to the digitally controlled actuator, it is possible to generate a great choice of user defined profiles opening the way to a wide choice of applications in the automotive and aerospace fields; offering near-to-reality testing conditions for pressure sensors and verification possibilities for pressure sensors based regulating electronic in hydraulic systems. An example of a tested pressure profile is given in Fig. 9: the pressure developed in a modern electro-hydraulic braking system of a car while decelerating from 14 to 0 m/s and simultaneously changing lane.

Further development offers interesting prospective for the enhancement of both dynamic pressure range and operating speed. Thanks to relative small dimension of the system an extension of the measurements in the temperature field is also possible.

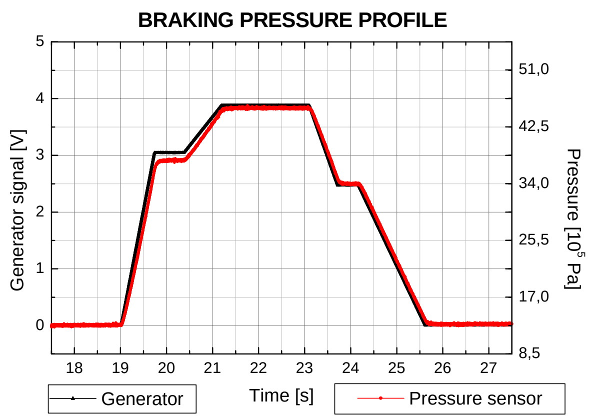

Fig. 9. Simulation of a pressure profile in a modern electro-hydraulic brake

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