New Materials for Production of Advanced Pneumatic and Hydraulic Valves

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Abstract

In this work we report the results of our investigation on new materials for the production of piston valves with much better dynamic properties and lesser energy consumption as compared to the traditional ones made of metals. Fiber reinforced polymer matrix composite materials with thin hard surface coatings have been developed and tested for manufacturing of hydraulic and pneumatic piston valves. The analysis has shown that the valves, actuated by a piezoelectric actuator consumes much less electric energy than the valve, actuated by the electro magnets and also achieves better dynamic characteristics.

Keywords: Advanced materials, pneumatic valve, hydraulic valve, polymer composites, hard surface coatings

1. Introduction

The pistons for hydraulic and pneumatic valves are usually made of steel and aluminium, respectively, and they are known for their relatively high density, which in turn influences negatively the valve dynamics, especially the response time [1, 2]. It is also known that the lower are the masses of the moving parts, the shorter is the switchover time and the overall dynamic response of the valve is better. In this work we report the results of our investigation on the influence of the material of the valve piston (i.e. moving part) on the valve dynamics. Several types of advanced materials have been developed for this purpose, based on polymer composites with thin hard coatings on the surface.

2. Experimental

2.1. Polymer composites

Following the main requirements for the valve piston: to be lighter than the metal counterpart; to withstand the working pressure of the valve; to be friction and abrasion resistant, several types of epoxy and phenolic resin fibre reinforced composites have been produced via filament winding or compression moulding techniques.

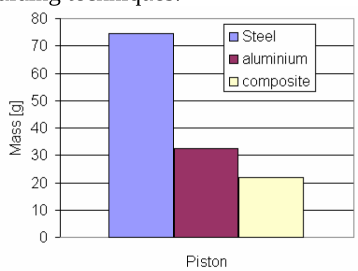

Fig. 1. Reduction of the mass of composite piston for hydraulic valve obtained by using polymer composite material

Their mechanical properties and surface roughness have been tested and the results are reported elsewhere [3, 4].

2.2. Hard coating

Various plasma technologies for surface treatment of the composites were used in order to create thin hard coating, such as PVD with different gases mixtures (oxygen, nitrogen and argon) and combination of PVD plasma etching and chemical activation procedure. After the etching and activation of the surface of the composite material, the first adhesive layer was deposited in order to provide a good adhesion between the coating and the composite material. Best results were achieved with the application of a complex alloy based on nickel. After deposition of adhesion layer, the deposition of the adopted coating which is characterized with high surface hardness and high wear and abrasion resistance was performed. In order to meet the required dimensional tolerance the thickness of the coating was fixed to max 10 µm. The composite pistons fabricated from polymer composite material with hard surface coating are shown in Figure 2.

Fig. 2. Prototypes of pneumatic (1) and hydraulic (2) pistons with hard surface coatings

2.3. Experimental setup

Measuring cycle for determination of the friction forces consists of one forward and one backward piston stroke. Five measuring cycles are carried out for a single stroke velocity. The static friction force has been determined by measuring the maximum friction force. To determine the Stribeck curve the sliding friction force is measured (see Fig. 3).

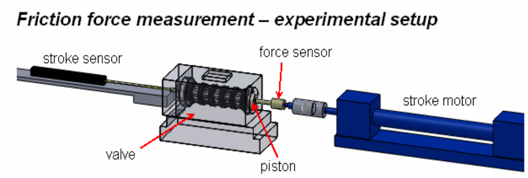

Fig. 3. Friction force measurement – experimental setup

Static properties of the pistons are determined prior the friction forces measurements, by measuring the mass of the pistons, their roughness, as well as dimensions and geometrical characteristics.

4. Results and discussion

The appropriate composite material for pneumatic and hydraulic valve is chosen on the basis of preliminary experiments carried out with nine different types of fibre reinforced composites, by measuring the static and dynamic characteristics of the pistons without hard surface coatings. Force comparison was made for all pistons at stroke speed of 30 mm/s (Fig. 4). The best results were achieved with composites that exhibited relatively low tensile modulus (E~20000 MPa), which, in turn, present the main problem in sense of piston deformation in hydraulic valves. Namely, the piston deformation (diameter contraction and the axial extension) was out of prescribed tolerance limit (6µm). By pilling up the thin surface coating on the composite piston followed by appropriate thermal treatment, the hardness was significantly improved, up to 710 $HV_{0.05}$ and appropriate requirements for the valves were successfully met.

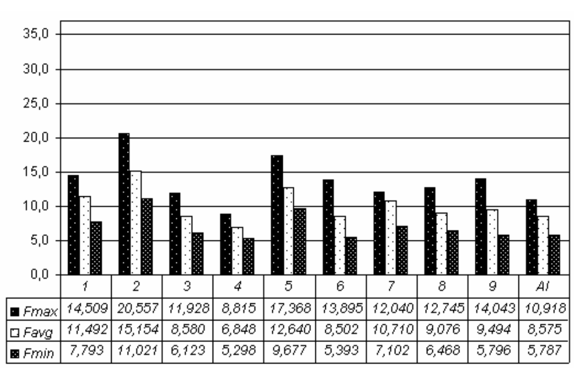

Fig. 4. Force (*F*, N) distribution measured on 9 pistons made of different composite materials compared to the Al-one (forward stroke, velocity 30 mm/s); *F*max-maximum force, static friction force; *F*avg-average sliding friction force; *F*min-minimum sliding friction force (depending on contact area size and deflections of piston or seals)

The results of investigation of dynamic properties for hydraulic valve made of polymer composite material with thin surface coating are presented in Table 1.

For comparison, the influence of type of actuator used is seen from the results obtained by using electromagnet instead of piezo-actuator: delay was 10 ms (compared to 4 ms in case of piezo-actuator) and stroke – 50-60 ms (compared to 38 ms).

Table 1. Dynamic properties of hydraulic valve made of composite material with hard surface coating and actuated by piezo-actuator

Material	Mass (g)	Stroke + delay (ms)	Frequency -3 dB (Hz)	Phase -90^o (Hz)
Composite with coating	22.0	17	34	17
Al	32.6	31	16	9.5
Steel	74.3	42	12	9

Total energy consumption of the valves was drastically reduced (from 8.96 W/h to 3.03x10-6 W/h) by replacing traditional electromagnets by piezo-actuators developed earlier [4].

6. Conclusion

Polymer composite materials with hard surface coating based on complex nickel alloy have been tested for manufacturing of advanced hydraulic and pneumatic valves actuated by piezo-actuators. Static and dynamic properties of the valves produced from different fiber reinforced epoxy and phenolic resin composites have been investigated, and the results have shown that the material used for the valve piston significantly influences the dynamics of the valve. By replacing metal pistons, traditionally used for pneumatic and hydraulic valves, with composite ones, the switchover and the response time of the valve decrease. Also, the consumption of energy has been drastically reduced by application of piezo-actuators instead of electromagnet.

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