AN INVESTIGATION OF ACOUSTIC NOISE GENERATED BY WATER FLOWING THROUGH NOZZLES

1. Introduction

Hydraulic systems, although they are fairly well-known in many aspects and are widely used in a variety of devices and machines, are still being improved in terms of performance parameters and acoustic parameters which accompany their operation. The most common working medium in such systems is hydraulic oil or water. In many driving systems of vehicles and working machines hydraulic oil is usually used as working medium [1, 2]. But water is commonly used in household appliances (washing machine, dishwasher, etc). In the last decade, particular attention is paid to the noise generated by the household appliances. The dominant source is water flowing through hydraulic systems. In the literature one will find examples of solutions reducing the noise generated by hydraulic systems operating at high pressure (over 10 MPa) [3, 4], or at low pressures (0.5 MPa) [5]. But it is still difficult to apply the results of these studies to hydraulic systems used in household appliances, e.g. to dishwashers where the water pressure is below 0.05 MPa.

In the article, authors present the results of investigation of a hydraulic system which is used in a dishwasher. The study is intended to identify the sources of noise in a hydraulic system, which can be generated by flow of water through the nozzles and hitting walls of a washing chamber of a dishwasher. The investigations show that noise generated by nozzles is generally dependent on the surface of the nozzle and hydraulic power. Further, the results of experimental studies will be used to minimize noise generated by the operating dishwasher.

2. Hydraulic system

Figure 1 presents general view of the washing chamber of the dishwasher with complete hydraulic system. The water flow and pressure is caused by a centrifugal pump which is located under the chamber. The water from the pump flow through the main water line (2) and is distributed into a lower spray arm (5) or the middle water line (3). Then, the water is split and flow through upper spray arm (6) and upper water line (4) ended with a sprinkler (7). The lower and upper spray arms have nozzles, which task is to wash dishes and force spray arm to rotate. The upper sprinkler is mounted permanently to chambers ceiling. The water flowing through the nozzles and the upper sprinkler goes back to the pump through the reservoir (1) and filter.

As it was already mentioned, the main elements of hydraulic system are: centrifugal pump and spray arms with nozzles. The centrifugal pump, which is used in standard dishwasher, provided by industrial partner, is shown in Figure 2. The pump is driven by

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an electric motor with constant rotation speed. In order to obtain the pump's hydraulic characteristic, on the outlet water line an adjustable throttle valve was mounted, which had allowed controlling flow of the water. The outlet water line was also fitted with a pressure sensor and a flow meter. In order to minimize influence of major and minor head losses the outlet water line, as well as inlet line, was connected directly to the external tank. The pump characteristic (Fig. 3) shows relationships between pressure and flow. Presented characteristic indicates that in wide range of the flow the pump pressure is almost kept on the constant level. The significant decrease of the pressure can only be observed in the range of high flow rates. In wide range the pump works almost as so called pressure generator.
A view of lower and upper spray arm with nozzles is presented respectively in Figure 4 and 5. On those Figures, nozzles are also marked with numbers, which were used during all performed analysis. A large number of nozzles doesn’t allow for simple identification of noise sources. So it was decided to build dedicated experimental setup which allowed investigating separately each nozzle with flow parameters as in the analysed dishwasher.

In order to identify values of hydraulic power, pressure and flow for each nozzle, using production hydraulic system, it was necessary to perform measurements in two stages. During the first stage volumes of the water flowing through every nozzle during certain period of time were measured. As a result it was possible to calculate values of
the flow in each nozzle. Figures 6 and 7 presents the experimental setup used during the first stage of measurements.

Fig. 6. A view of experimental setup used to measure a flow rate in a lower spray arm

Fig. 7. A view of experimental setup used to measure a flow rate in an upper spray arm

Analysis of the results indicates that the value of water flow rate in majority of nozzles is in the range from 0,8 to 2,5 dm$^3$/min. Only in nozzle No. 21 (cf. Fig. 5), which is responsible for rotation of lower spray arm, the water flow rate was higher and equal to 4,7 dm$^3$/min. The total flow rates of the water flowing through following sections are following: lower spray arm about 22 dm$^3$/min, upper spray arm 19 dm$^3$/min, sprinkler about 9 dm$^3$/min. The total flow rate of the pump working with nominal voltage is about 50,5 dm$^3$/min. This means that the pump operates at maximum flow rate (cf. Fig. 3).

In the second stage pressures inside spray arms near outlet of selected nozzles were measured. During these investigations, the production hydraulic system with the production control unit was used. The values of pressure were measured with electronic pressure sensors attached to hydraulic hoses and placed on the same vertical level as nozzles. The experimental setup used in the second stage is shown in Figures 8 and 9. In the same way authors measured the value of pressure in water lines and before the
sprinkler. Numbers in Figures 8 and 9 refer to pressure measurement points located on spray arms.

Fig. 8. A view of experimental setup used to measure a pressure in a lower spray arm (description in text)

Fig. 9. A view of experimental setup used to measure a pressure in an upper spray arm (description in text)

The results indicate that pressure along the length of the upper spray arm varies slightly around the average pressure that is 0,07 bar higher relative to atmosphere pressure. Similar effect can be observed in the lower spray arm where average pressure is equal 0,19 bar. Pressure was also measured in all water lines and is respectively equal: 0,20 bar in the lower line, 0,13 bar in the middle line, 0,08 bar in the upper line and 0,07 bar just before the sprinkle.

Based on the obtained results of experimental investigation it was possible to determine hydraulic power $N_H$ [W] of water flowing through each part of hydraulic system according to the formula:

$$N_H = Q \cdot \Delta p$$ (1)

where: $Q$ – flow rate [m$^3$/s], $\Delta p$ – difference pressure [Pa] (overpressure, in case of nozzles difference between measured pressure in spray arms and atmospheric pressure).

The above results of experimental investigation were used to design and build dedicated experimental setup which allowed for investigation of individual nozzle noise.
separately from impact of others. The results presented below were obtained using this experimental setup for the nozzles No. 6 and No. 16 (cf. Fig. 4 and 5). The nozzle No. 6 is placed in the upper spray arm and has flow rate 1,81 dm³/min at the factory setting of the pump while the nozzle No. 16 is placed in lower spray arm and flow rate is equal 2,03 dm³/min. The cross section area of nozzle No. 6 and No. 16 is equal adequately 7,67 mm² and 5,95 mm². Taking into account the relationship (1) it can be calculated that hydraulic power of water flowing in the nozzle No. 6 is 0,211 W and in the nozzle No. 16 is 0,643 W.

3. Investigation of a sound pressure level (SPL)

The mentioned above experimental setup, was also designed in such a way that it is possible to measure noise generated by nozzle in the form of the sound pressure level (SPL) with A-weighting using waterproof microphone sensor. The experimental setup was also covered externally and internally with noise dampening materials preventing influence of external sources on measurements.

The nozzles were cut off from spray arms and were mounted in a specially designed handle with attached hydraulic system which allowed simulating different hydraulic conditions resulting from wide range of flow parameters and pressures. The water flowing out from the nozzle was hitting a circular plate having a diameter of 100 mm, thickness about 1 mm and made of duralumin. The SPL, pressure and flow rate were measured using electronic sensors.

Figure 10 presents the results of the noise level (SPL) in function of water flow rate for two nozzles No. 6 and No. 16. Presented flow rate range (0,58 - 3,91 dm³/min) covers the range of flow rates observed in analysed dishwasher and equal respectively 1,81 dm³/min for the nozzle No. 6 and 2,03 dm³/min for the nozzle No. 16. It can be observed that SPL is lower for the nozzle No. 16 then for No. 6 with the same flow rate but the difference is not large and varies from 1 dB up to 5 dB.

![Fig. 10. SPL in function of the flow rate](image)

The values of the SPL in function of difference pressure are presented in Figure 11. The pressure varies in range 0 – 0,56 bar. This range include pressures observed in factory hydraulic system of the dishwasher - 0,07 bar for nozzle No. 6 and 0,19 bar for nozzle No. 16. It can be observed that SPL is lower for the nozzle No. 6 then for No. 16.
with the same value of the pressure. The difference is larger than in previous case and range from 3 dB up to 20 dB.

Figure 12 presents the results of the measured SPL as function of hydraulic power. Figure 12 shows that relationship is almost the same for both nozzles but noise generated by the nozzle No. 6 is little bit lower than noise generated by the nozzle No. 16 at the same values of the hydraulic power. The hydraulic power in factory hydraulic system is equal 0,211 W in nozzle No. 6 and 0,643 W in the nozzle No. 16. The analysis of the results of experimental studies indicates that the SPL increases with the value of the hydraulic power but the difference for both nozzles is not large and varies up to 3 dB.

![Fig. 11. SPL in function of the pressure](image1)

![Fig. 12. SPL in function of the hydraulic power](image2)

4. Conclusions

The publication presents results of preliminary investigations of the sound pressure level (SPL) as parameter of noise generated by the productive hydraulic system of the
dishwasher. The determined parameters of the hydraulic system were used to design and build experiment setup required investigating the SPL of selected nozzles. The results indicate that: the SPL in function of the flow rate, the pressure and the hydraulic power can be used for benchmarking different types of nozzles. The main difference in the values of SPL can be observed in relationship to the pressure. It must be remembered that the cross section area of the nozzle No. 6 is larger. This means that it is probably possible to lower the SPL by using the nozzle with larger cross section area for the same value of the hydraulic power. However the value of cross section area affects water pressure and velocity. Also a value of corresponding hydraulic losses in the nozzle is affected which depend on a quadratic function of water velocity. The results also indicate that lower values of the SPL caused by the flow out of water from the nozzles and hitting the plate can be achieved by reducing the hydraulic power. Future research will be focused on investigation of the influence of nozzles geometry on the value of SPL.

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References:


Abstract

In the paper, authors present the results of an experimental investigation of influence of nozzle shape and cross section area on the value of emitted noise in a low pressure (less than 0,05 MPa) hydraulic system. The experimental studies are carried out using the hydraulic system of a dishwasher. During investigations, the characteristics of the hydraulic system are obtained. Based on obtained results, a new experimental setup was designed to investigate the noise of water flowing from different nozzles.
The publication also presents the results in the form of characteristics showing the relationship between the sound pressure level (SPL) and pressure, flow and hydraulic power of water flowing through different nozzles. The results show that an increase of the hydraulic power is accompanied by an increase of SPL and that SPL can be lowered by using the nozzle with a larger surface area.

**Keywords:** hydraulic system, nozzle, noise level, experimental investigation, dishwasher

**BADANIA POZIOMU HAŁASU EMITOWANEGO PRZEZ WODĘ PRZEPŁYWAJĄCA PRZEZ DysZE ZMYWARKI**

**Streszczenie**

W artykule przedstawiono wyniki badania wpływ kształtu i rozmiaru dyszy na wartość emitowanego hałasu przy niskim ciśnieniu (poniżej 0,05 MPa) układu hydraulicznego. Badania eksperymentalne były przeprowadzane przy użyciu fabrycznie nowego układu hydraulicznego zmywarki do naczyń. W trakcie badań, otrzymano charakterystyki układu hydraulicznego. Na tej podstawie, zbudowano nową doświadczalną instalację hydrauliczną z wykorzystaniem której zbadano hałas wody płynącej z różnych dysz.

Wyniki przedstawiono również w postaci charakterystyk przedstawiających zależność pomiędzy poziomem hałasu (SPL) w funkcji parametrów hydraulicznych: ciśnienia, przepływu i mocy hydraulicznej. Wyniki badań wskazują, że zwiększeniu siły hydraulicznej towarzyszy wzrost poziomu ciśnienia akustycznego SPL, który można obniżyć za pomocą dyszy o większym polu powierzchni.

**Słowa kluczowe:** układ hydrauliczny, dysza, poziom hałasu, badania eksperymentalne, zmywarka do naczyń