

FORMALIZING THE PROCEDURE FOR DEFINING ACOUSTIC ACTIVITY OF THE GEAR PUMP IN A PROTOTYPE PHASE

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Abstract: This research deals with the investigation of the acoustic activity in determination of the sound power level and the sound pressure level of the prototype of oil hydraulic gear pump designed for the fluid transport under high pressure.

The International Standards based on the sound pressure measurements without exception specify sound pressure level as the primary acoustic quantity to be measured. The procedures specified in ISO 3740 series are not always appropriate, for the following reasons:

- Costly facilities are necessary if high precision is required. It is frequently not possible to install and operate large pieces of equipment in such facilities
- They cannot be used in the presence of high levels of extraneous noise generated by sources other than under investigation.

In the study presented shown in this paper ISO 9614-1 is enforced as the standard that gives the methods for determination of the sound power level of noise sources in specified measurement uncertainty and test conditions less restrictive than conditions in ISO 3744 series.

Key words: Sound Intensity, Sound Power, Gear Pump

1. INTRODUCTION

Previous International Standards which describe methods of determination of sound power level of noise sources, principally ISO 3740 to ISO 3747, without exception specify sound pressure level as the primary acoustic quantity to be measured. The procedures specified in ISO 3740 to ISO 3747 are not always appropriate, for the following reasons:

- Costly facilities are necessary if high precision is required. It is frequently not possible to install and operate large piece of equipment in such facilities
- They cannot be used in the presence of high levels of extraneous noise generated by source other then under investigation.

Because of that ISO 9614 is developed. The purpose of ISO 9614 is to specify methods whereby the sound power levels of sources may be determined, within specific ranges of uncertainty, under test condition which are less restricted than those required by series ISO 3740 to ISO 3747.

ISO 9614 gives a method for determining the sound power level of a source of stationary noise from measurements of sound intensity on a surface enclosing the source. The method is based on the fact that the integral over any surface totally enclosing the source of the scalar product of the sound intensity vector and the associated elemental area vector provides a measure of the sound power radiated by all sources located within the enclosing surface, and it excludes sound radiated by sources located outside this surface. The one-octave and third-octave or band-limited weighted sound power level is calculated from the measured values. The method is applicable to any source for which a physically stationary measurement surface can be defined, and on which the noise generated by the source is stationary in time. Also, the method is applicable *in situ* or in special purpose test environments.

ISO 9614 specifies certain ancillary procedures to be followed in conjunction with the sound power determination. The results are used to indicate the quality of the determination and hence grade of accuracy. If the indicated quality of the determination does not meet the requirements of ISO 9614, the test procedure should be modified in the described manner.

2. DEFINITIONS

Sound pressure level, L_p – Ten times the logarithm to the base 10 of the ratio of the mean-square sound pressure to the square of the reference sound pressure. The reference sound pressure is $20\mu\text{Pa}$. Sound pressure level is measured in decibels.

Instantaneous sound intensity, $\vec{I}(t)$ – Instantaneous rate of flow of sound energy per unit of surface area in the direction of the local instantaneous acoustic particle velocity. This is a vector quantity which is equal to the product of the instantaneous sound pressure at a point and the associated particle velocity:

$$\vec{I}(t) = p(t) \cdot \vec{u}(t) \quad (1)$$

where: $p(t)$ is the instantaneous sound pressure at a point;

$\vec{u}(t)$ is the associated instantaneous particle velocity at the same point;

t is the time.

Sound intensity, $\bar{I}(t)$ – Time-averaged value of $\vec{I}(t)$ in a temporally stationary sound field:

$$\bar{I} = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T \vec{I}(t) dt \quad (2)$$

where: T is the integration period, I is the signed magnitude of \bar{I} ; the sign is an indication of directional sense, and is dictated by the choice of positive direction of energy flow; $|I|$ is the unsigned magnitude of \bar{I} .

Normal sound intensity, I_n - Component of the sound intensity in the direction normal to a measurement surface defined by the unit normal vector \vec{n} :

$$I_n = \vec{I} \cdot \vec{n} \quad (3)$$

where: \vec{n} is the unit normal vector directed out of the volume enclosed by the measurement surface.

Normal sound intensity level, L_{I_n} – Logarithmic measure of the unsigned value of the normal sound intensity $|I_n|$, given by:

$$L_{I_n} = 10 \log[|I_n| / I_0] \text{ dB} \quad (4)$$

where: $I_0 = 10^{-12} \text{ W/m}^2$ is the reference sound intensity. It is expressed in decibels.

When I_n is negative, the level is expressed as $-XX \text{ dB}$, except when used in the evaluation of $\delta_{P_{I_0}}$.

Partial sound power P_i – Time-averaged rate of flow of sound energy through an element of a measurement surface, given by:

$$P_i = \vec{I}_i \cdot \vec{S}_i = I_{ni} \cdot S_i \quad (5)$$

where: I_{ni} is the signed magnitude of the normal sound intensity component measured at position i on the measurement surface;

S_i is the area of the segment of surface associated with point i .

Sound power, P : Total sound power generated by a source as determined using the method given in ISO 9614,

$$P = \sum_{i=1}^N P_i \quad (6)$$

and

$$|P| = \left| \sum_{i=1}^N P_i \right| \quad (7)$$

where: N is the total number of segments of the measurement surface.

Sound power level, L_W : Logarithmic measure of the sound power generated by a source,

$$L_W = 10 \log \frac{|P|}{P_0} \text{ dB} \quad (8)$$

where: $|P|$ is the magnitude of the sound power of the source;

$P_0 = 10^{-12} \text{ W}$ is reference sound power.

Sound power level is expressed in decibels. When P is negative, the level is expressed $-XX \text{ dB}$. The standard is not applicable if the value of P of the source is found to be negative.

3. GENERAL REQUIREMENTS

a) Size of noise source

The size of the noise source is unrestricted. The extent of the source is defined by the choice of the measurement surface.

b) Character of noise radiated by the source

The signal shall be stationary in time. If a source operates according to a duty cycle, within which there are distinct continuous periods of steady operation, an individual sound power level is determined and reported for each distinct period. Action shall be taken to avoid measurement during times of operation of non-stationary extraneous noise sources of which the occurrences are predictable.

c) Measurement uncertainty

The stated uncertainties account for random errors associated with the measurement procedure, together with the maximum measurement bias error which is limited by the selection of the bias error factor K appropriate to the required grade of accuracy. They do not account for tolerances in nominal instrument performance, nor do they account for the effects of variation in source installation, mounting and operating conditions.

The normal range for A-weighted data is covered by the one-octave band from 63 Hz to 4 kHz and the one-third-octave bands from 50 Hz to 6.3 kHz.

The uncertainty in the determination of the sound power level of a noise source is related to the nature of the sound field of the source, to the nature of the extraneous sound field, to the absorption of the source under test, and to the type of intensity-field sampling and measurement procedure employed. For this reason, the standard specifies initial procedure for the evaluation of the nature of the sound field which exists in the region of the proposed measurement surface.

d) Level of extraneous intensity

It is necessary to minimize the level of extraneous intensity in such a way so as not to reduce unacceptability. The variability of the extraneous noise intensity shall not be such that the specified limit on sound field variability indicator, F_1 , is exceeded.

e) Wind, gas flow, vibration and temperature

Measurements should not be made when air flow conditions in the vicinity of the intensity probe contravene the limits for the satisfactory performance of the measurement system. A probe windscreens shall be always used during outdoor measurements. The probe should not be placed in, or very close to, any stream of flowing gas whose mean speed exceeds 2 m/s.

The probe should not be placed closer than 20 mm to bodies having a temperature significantly different from the ambient air, especially if there is a high temperature gradient across the probe.

f) Instrumentation

A sound intensity instrument and probe that meet the requirements of IEC 1043 shall be used. To check the instrumentation for proper operation prior to each series of measurement the field-check procedure specified by the manufacturer shall be applied.

g) Installation and operation of the source

The source shall be mounted or placed in a proper way representative of normal use or the way stated in a special test code for the particular type of machinery or equipment.

The operating and mounting conditions specified in a test code, if any, for the particular type of machinery or equipment shall be used. If there is no test code, the source heavily loaded in a steady condition representative of normal use shall be operated.

4. MEASUREMENT OF NORMAL SOUND INTENSITY COMPONENT LEVELS

a) *Averaging time*

For 95% confidence level of a maximum error of 5% in measured intensity, the averaging time requirement for instruments using filters for white noise with Gaussian distribution is given by

$$BT \geq 400 \quad (9)$$

where: B is the filter bandwidth, and T is the averaging time.

b) *Field indicators*

Temporal variability indicator of the sound field

A typical value of the temporal variability indicator, F_1 , of the sound field at an appropriate position selected on the measurement surface is given by:

$$F_1 = \frac{1}{I_n} \sqrt{\frac{1}{M-1} \sum_{k=1}^M [I_{nk} - \bar{I}_n]^2} \quad (10)$$

where: \bar{I}_n is the mean value of I_n , for M short-time average samples I_{nk} calculated from equation:

$$\bar{I}_n = \frac{1}{M} \sum_{k=1}^M I_{nk} \quad (11)$$

Number of measurement M will normally take a value of 10, and a recommended short averaging time is between 8s and 12s or any integer number of cycles for periodic signals.

Surface pressure-intensity indicator

The surface pressure-intensity indicator, F_2 , can be calculated from equation:

$$F_2 = \overline{L_p} - \overline{L_{|I_n|}} \quad (12)$$

where: $\overline{L_p}$ is the surface sound pressure level, in dB, calculated from equation:

$$\overline{L_p} = 10 \log \left[\frac{1}{N} \sum_{i=1}^N 10^{0.1 L_{pi}} \right] \quad (13)$$

and $\overline{L_{|I_n|}}$ is the surface normal unsigned intensity level, in dB, calculated from equation

$$\overline{L_{|I_n|}} = 10 \log \left[\frac{1}{N} \sum_{i=1}^N |I_{ni}| / I_0 \right] \quad (14)$$

where: $|I_{ni}|$ is the unsigned normal sound intensity at measurement position i .

■ *Negative partial power indicator*

The negative partial power indicator, F_3 , can be calculated from equation:

$$F_3 = \overline{L_p} - \overline{L_{I_n}} \quad (15)$$

where $\overline{L_{I_n}}$ is the surface sound pressure level, in dB, calculated from equation:

$$\overline{L_{I_n}} = 10 \log \left| \frac{1}{N} \sum_{i=1}^N I_{ni} / I_0 \right| \quad (16)$$

where I_{ni} is the signed magnitude of the normal sound intensity component measured at position i on the measurement surface, and $I_0 = 10^{-12} \text{ W/m}^2$ is the reference sound intensity.

If the normal sound intensity component level $L_{I_{ni}}$ at position i is expressed as XXdB, I_{ni} can be calculated from equation:

$$I_{ni} = I_0 \times 10^{XX/10}$$

If the normal sound intensity component level $L_{I_{ni}}$ at position i is expressed as -XXdB, I_{ni} can be calculated from equation:

$$I_{ni} = -I_0 \times 10^{XX/10}$$

If $\Sigma I_{ni} / I_0$ is negative in any frequency band, the test conditions do not satisfy the requirements of standard in that frequency band.

■ *Field non-uniformity indicator*

The field non-uniformity indicator, F_4 , can be calculated from equation:

$$F_4 = \frac{1}{\overline{I_n}} \sqrt{\frac{1}{N-1} \sum_{i=1}^N [I_{ni} - \overline{I_n}]^2} \quad (17)$$

where: $\overline{I_n}$ is the surface normal sound intensity calculated from equation:

$$\overline{I_n} = \frac{1}{N} \sum_{i=1}^N I_{ni} \quad (18)$$

5. CALCULATED OF SOUND POWER LEVEL

a) *Calculation of partial sound powers for each segment of the measurement surface*

A partial sound power in each frequency band for each segment of the measurement surface can be calculated from the equation:

$$P_i = I_{ni} S_i \quad (19)$$

where P_i is the partial sound power for segment I , I_{ni} is the signed magnitude of the normal sound intensity component measured at position I on the measurement surface, S_i is the area of segment i .

b) Calculation of the sound power level of the noise source

The sound power level of the noise source in each frequency band can be calculated from equation:

$$L_W = 10 \log \sum_{i=1}^N P_i / P_0, \text{ dB} \quad (20)$$

where P_i is the partial sound power for the segment I ,

$P_0 = 10^{-12}$ dB is the reference sound power, and

N is the total number of measurement positions and segments.

If $\sum_{i=1}^N P_i < 0$ is negative in any frequency band, the method given in ISO 1996 is not applicable to that band.

6. RESULTS OF INVESTIGATION

6.1 Sound power of the gear pump

The sound power of the tested gear pump has been determined using the sampling method of normal component of the sound intensity according to ISO 9614-1.

6.2 Installation and operation of the gear pump

The gear pump has been mounted on the test table which construction is shown in Fig. 1. The operating and mounting conditions have been representative of normal use of the gear pump.

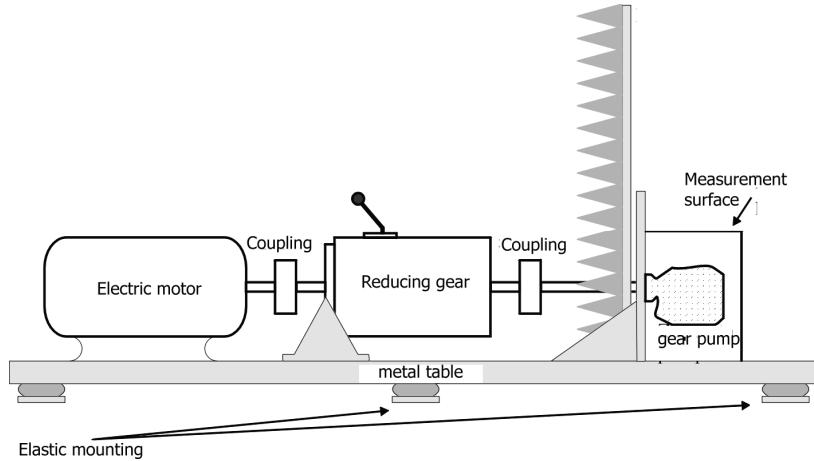


Fig. 1 Test table

According to stated the nominal and maximum value of RPM and pressure, the gear pump has been tested for the six operation regime with the following parameters:

- 1150-100: $n=1150$ r.p.m, $p=100$ bar;
- 1150-150: $n=1150$ r.p.m, $p=150$ bar;
- 1150-200: $n=1150$ r.p.m, $p=200$ bar;
- 1900-100: $n=1900$ r.p.m, $p=100$ bar;
- 1900-150: $n=1900$ r.p.m, $p=150$ bar;
- 1900-200: $n=1900$ r.p.m, $p=200$ bar.

6.3 Measurement environment

The test table with the gear pump has been placed in the rectangular room of volume of 36000m^3 . The surface of oil tank has been noticed in near the test table as the reflected surface which can reduce measurement accuracy. Because of that, that surface has been covered by absorption material in form of rock wool table of thickness of 50mm.

There has not been extraneous acoustic emission during the testing except the test table component. In order to reduce influence of acoustic emission of the test table component (electric motor and low-range gear lever) on the accuracy of measurement of the sound intensity at the measurement surface, the measurement surface has been separated from noticed components with the wood table covered by rock wool table of thickness of 50mm.

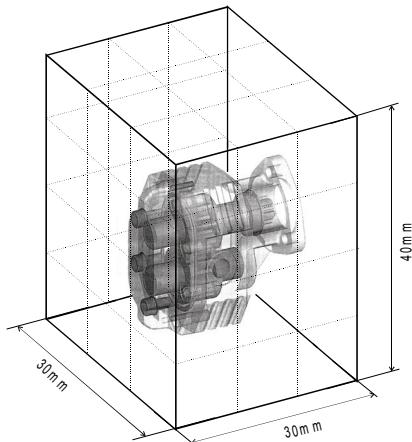


Fig. 2 Measurement surface

6.4 Measurement surface

The measurement surface has been defined around the source under test – the gear pump in the geometrically simple form of rectangular surface with dimension of $300\times300\times400\text{mm}$. The measurement surface has been included two totally reflected surfaces – the lower and back surface. The sound intensity has not been measured at those surfaces. The remaining measurement surface has been divided into 45 segments of $100\times100\text{mm}$. The normal component of the sound intensity has been measured in the centre of surface segments. The results obtained in the measurement procedure are shown in Fig. 3 – Fig. 5.

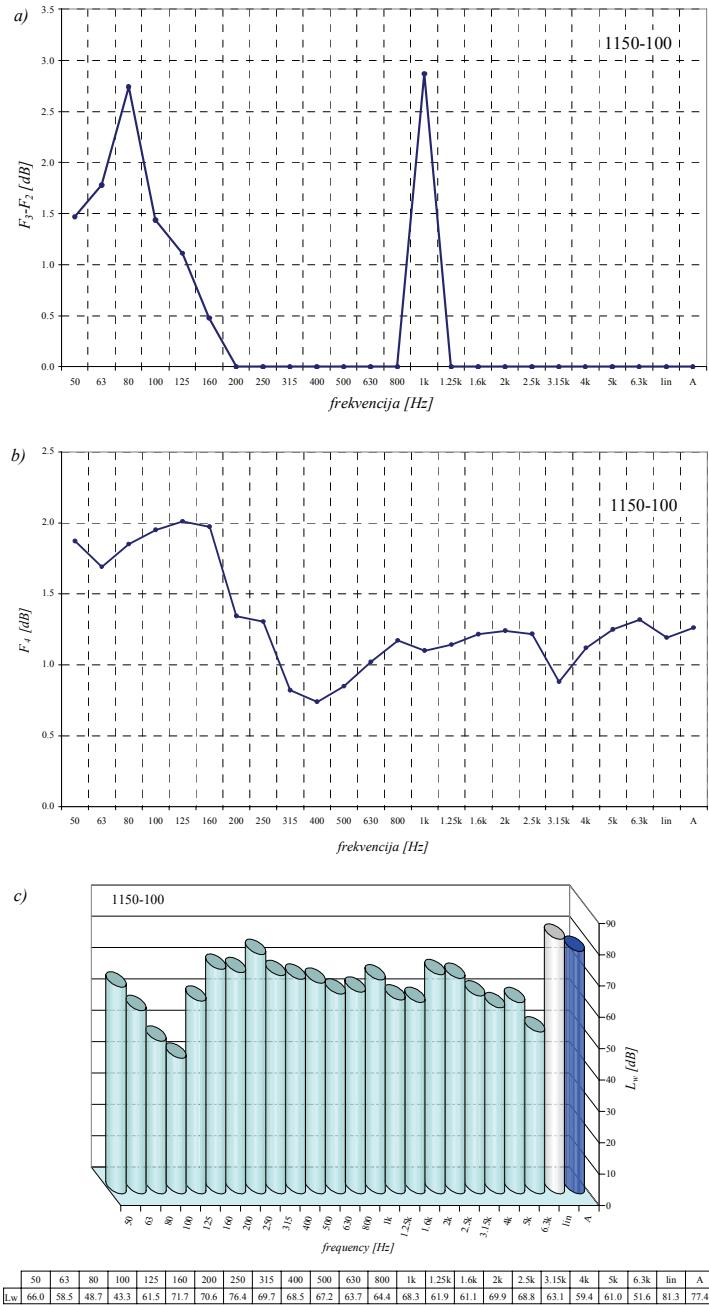


Fig. 3 Operation regime of gear pump 1150-100;

- a) Difference surface pressure-intensity indicator and negative partial power indicator;
- b) Field non-uniformity indicator; c) Sound power level

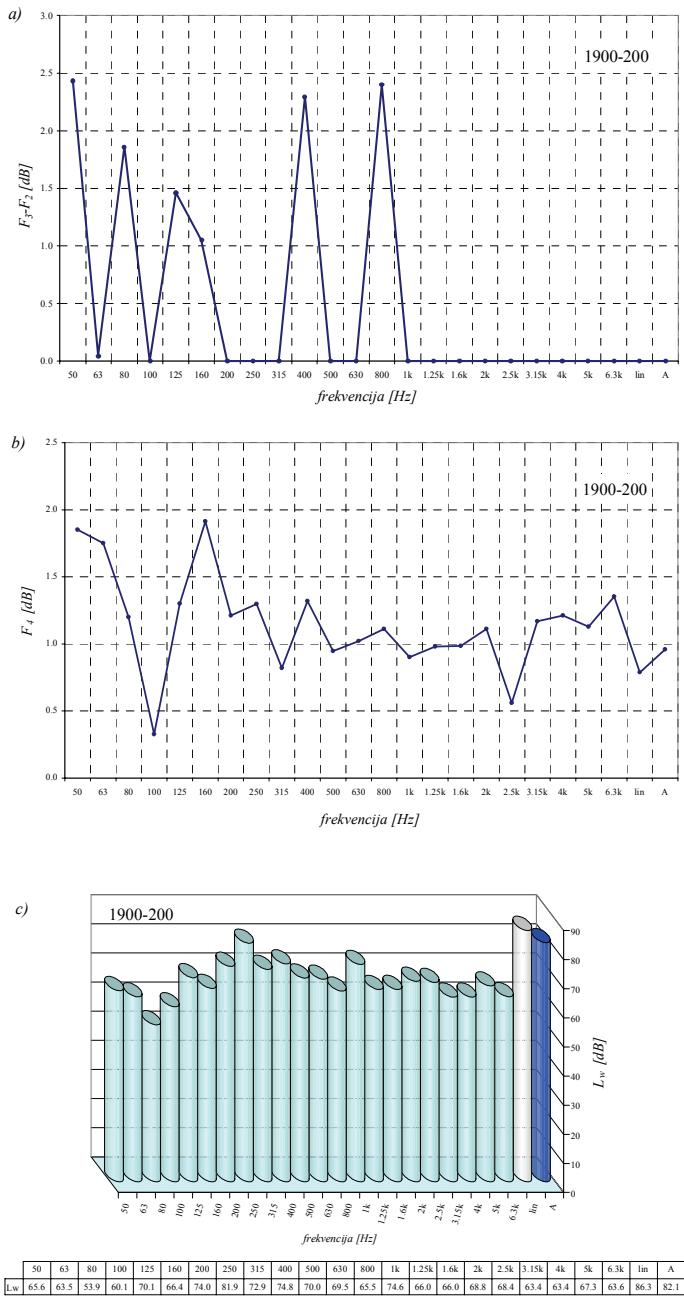


Fig. 4 Operation regime of gear pump 1900-200;

- a) Difference surface pressure-intensity indicator and negative partial power indicator;
- b) Field non-uniformity indicator;
- c) Sound power level

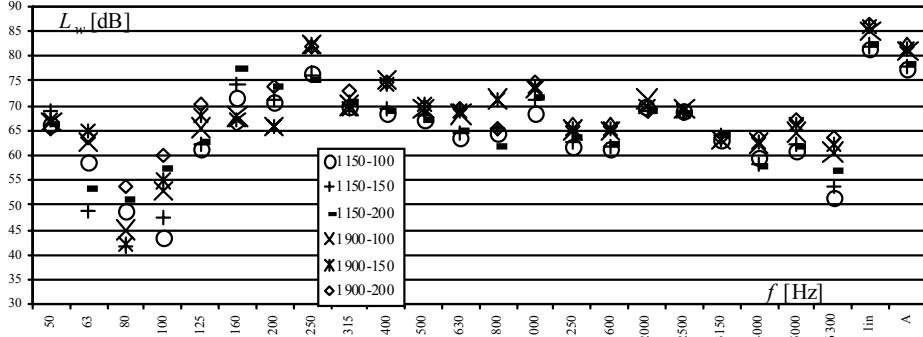


Fig. 5 Sound power level of the gear pump for all tested operation regime

7. CONCLUSION

The sound intensity as a vector quantity offers the possibility for determining acoustical quantity of a complex machine structure *in situ*, with much more flexibility in the choice of measurement environment and size of test object (as used to be the limitation and disadvantage of classical methods) by applying sound pressure measurement. The sound intensity measurements may be used to localize noise sources and to construct intensity maps showing regions of high and low noise radiation and also the direction of the energy flux. The shown example of the sound intensity measurement on the gear pump indicates that the sound intensity technique is a very reliable tool for identification and valorization of the acoustic activity of the gear pump in a prototype phase.

Deviation of measurement environment from free-field condition defined by the reactivity index determined as the difference of sound pressure level and sound intensity level in the specified measurement position determine measurement sound intensity error.

The sound field reactivity had the least values for the measurement points located in direct field of noise source radiation, a little larger value in the near field and the largest values in the reverberation field. Also, the sound field reactivity had the least values for the frontal orientation of noise source relative to the measurement point and the larger values when the sound source is rear-directed toward measurement point.

The increasing sound field reactivity causes the increasing measurement sound intensity error. For sound field reactivity values ranging below 8dB, the measurement error will be ± 1 dB. For sound field reactivity values ranging from 8dB to 10dB, the measurement error will be ± 2 dB. And for sound field reactivity values ranging under 10dB, the measurement error will be greater than ± 2 dB.

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**FORMALIZOVANJE PROCEDURA ZA DEFINISANJE
AKUSTIČKE AKTIVNOSTI ZUPČASTE PUMPE U FAZI
RAZVOJA PROTOTIPA**

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Predmet istraživanja je ispitivanje akustičke aktivnosti kroz određivanje nivoa zvučne snage i definisanje nivoa zvučnog pritiska, prototipa uljno-hidraulične zupčaste pumpe namenjene za transport fluida pod visokim pritiskom.

Međunarodni standardi zasnovani na procedurama merenja zvučnog pritiska bez izuzetka navode nivo zvučnog pritiska kao primarnu mernu akustičku veličinu. Standardizovane procedure definisane u standardima serije ISO 3740 nisu uvek odgovarajuće iz sledećih razloga:

- *Ukoliko se zahteva visoka preciznost pri merenju - neophodni su skupi objekti i sredstva, a često nije moguće instalirati i pustiti u rad velike mašine i delove opreme u takvim objektima.*
- *Ne mogu se koristiti u ambijentu sa visokim nivoom pozadinske buke.*

U istraživanjima koja su prikazana u radu primjenjen je standard ISO 9614-1 čija je namena definisanje metoda pomoću kojih se može odrediti nivo zvučne snage izvora, u definisanim opsezima nesigurnosti, sa test uslovima koji su manje restriktivni od uslova zahtevanih u seriji standarda ISO 3740.

Ključne reči: *Intenzitet zvuka, zvučna snaga, zupčasta pumpa*