Search of Noise Source of Spiral Vacuum Pump

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Abstract—A Spiral vacuum pump is widely used in a low noise type suction truck. When the pump is operated, a large gear noise generates and some countermeasures are required. Then it is necessary to search the noise source position for countermeasure. Several studies are conducted to search the noise source position. As a result, it was clarified that the noise source position was not from the gear casing which is immediately think up but from an elbow near the spiral vacuum pump. In order to clarify the result, the noise source search was performed by using the current searching technique (Sound Brush made by LMS) which is 3D intensity meter and we confirmed it.

Index Terms—Noise source search, Spiral vacuum pump, Acoustic intensity, Suction truck

I. INTRODUCTION

The low noise suction truck which is the product of A company uses a spiral vacuum pump to reduce the noise. The reason is that the spiral pump is generally said to be low noise. The high level sound was generated when the spiral pump was operated. In general, the main noise source is a gear noise generated from the gear which transmits the power from driving shaft to the following shaft [4]-[8]. Then the gear noise is thought to be transmitted from the gear casing. We therefore thought that the transmitted noise can be reduced by changing the material of the casing from the aluminum to the cast steel. But it was proved that the gear noise could not be reduced by measuring the noise after changing the material. This fact means the noise source is not the transmitting noise from the gear casing and it was needed to know where the true noise source was. In this paper, it will be described that some examinations are conducted in order to clarify the true noise source.

II. EXPERIMENT

Figure1 shows the experimental equipment. The noise was measured by use of the noise meter (NL-42, made by Rion company) and the noise detection was performed by using the Sound Brush made by LMS.

The measurement was carried out as follows.
1. The power was taken out from a motor and the pump is rotated. The rotating speed is set at 2400rpm.
2. The valve attached the suction piping is gradually closed and the vacuum pressure is measured by the mercury manometer (Set pressure : -700[mmHg](≒-93[kPa])). At this time the cooling water is taken out from the tap water and the flow rate is set constant.
3. The sound pressure level was measured and investigated by the noise meter. The noise with the fundamental frequency of 1960Hz made by the gear was generated. Where the fundamental frequency of the gear is calculated by \( f = \frac{n}{49} \times N \) (n: Rotating speed [rpm]=2400, N : Number of gear teeth =49)
4. It was judged from the sense of hearing actually and the measurement result that the noise was transmitted not from the gear casing but from the elbow of the suction piping.
5. In the state that the elbow part was covered by the blanket, the noise was measured at the point 1m apart from the pump surface and frequency analyzed.

Figure2 shows the spectrum result of the noise level measured at the discharge piping side under the condition of with /without blanket. Figure3 shows the enlarged view of Figure2. From this figure, it was clarified that the blanket suppressed the noise 13.5dB of 1960Hz component which is the gear noise.

That is to say, it was confirmed that the noise of 1960Hz component can be reduced by preventing the transmitting noise from the elbow. However, the noises of 1920Hz, 2000Hz, and 2040Hz could not be reduced. These frequencies...
III. NOISE SOURCE EXPLORATION

The Sound Brush made by LMS company used here to explore the noise source. It can visualize the noise real timely by combining the 3D acoustic intensity and the noise exploration. We can obtain the detail results such as the acoustic intensity, acoustic propagation and acoustic power value there.

A. Measurement principle of acoustic intensity

The acoustic intensity is the acoustic energy passing through the unit area per unit time. The unit is \( W/m^2 \).

Describing the sound pressure by \( p(t) \) and the particle velocity by \( u(t) \) at the measuring point, the acoustic intensity is defined by time average of product of the both physical quantities.

As the particle velocity is the vector quantity and the sound pressure is the scalar quantity the acoustic intensity becomes the vector quantity. Here the sound pressure and the particle velocity are given as follows [3],[4].

\[
P_m(t) = \frac{p_1(t) + p_2(t)}{2}
\]

(1)

\[
u_m(t) = -\frac{1}{\rho} \int_{T/2}^{T/2} (p_2(t) - p_1(t)) dt
\]

(2)

Therefore, the acoustic intensity \( I \) becomes the next equation.

\[
I = \lim_{T \to \infty} \int_{-T/2}^{T/2} p(t)u(t)dt
\]

(3)

Substituting Eq. (1) and (2) into Eq. (3)

\[
I = \lim_{T \to \infty} \int_{-T/2}^{T/2} \frac{p_1(t) + p_2(t)}{2} \int_{-T/2}^{T/2} (p_2(t) - p_1(t)) dt dt
\]

(4)

can be obtained. Where \( T \) is a time.

In many intensity measuring instrument, almost all the acoustic intensity can be obtained in the frequency domain.

Fourier transforming Eq. (4), the acoustic intensity can be obtained by the imaginary part of the cross spectrum calculated by use of two sound pressures \( p_1(t) \), \( p_2(t) \) measured by two microphones. Where \( \omega \) is the angular frequency.

\[
I = \int_{-\infty}^{\infty} I(\omega) d\omega
\]

(5)

\[
I(\omega) = \frac{I_m [G21(\omega)]}{\rho \Delta \omega}
\]

(6)

(See APPENDIX A)

The acoustic intensity of frequency range \( B \) which is prescribed by lower and upper limit given \( \omega_1 \), \( \omega_2 \) can be given the next equation.

\[
I(B) = \int_{\omega_1}^{\omega_2} I(\omega) d\omega
\]

(7)

In 3D acoustic intensity measurement, the acoustic intensity of \( x \), \( y \), \( z \) directions can be obtained by deploying four microphones ( ) as shown in figure 3.

B. Measurement result due to acoustic intensity

The result of the noise detection conducted from discharge side is shown in figure 4.

It can be seen from the figure 4 by focusing the vector of the side of gear casing that the noise distribution is not outer from the surface of gear casing but parallel to the gear casing uniformly.
It is presumed that this noise is not from the pump but from the motor located side of the pump.

And the position of the highest level noise is the upper part of the flange of suction side this position is near the elbow not shown in the figure.

Fig.4 Vector distribution of acoustic intensity due to Sound Brush

VI Conclusions

The noise detection was performed to reduce the environmental noise of the gear casing. As a result, the following findings can be obtained,

(1) The transmitting noise from the gear casing can’t be seen in this experiment. Therefore, the change of material from aluminum to cast steel has not merit.

(2) The noise reduction effect can be seen to raise the thick of piping and to use the absorbing material. Because the transmitting gear noise from the suction piping is large.

(3) The acoustic intensity distribution around the gear casing was measured by use of the Sound Brush made by LMS company which is the latest noise detection instrument. As a result, it was clarified that the gear noise was generated not from the gear casing but from the elbow.

(4) The gear noise transmitted from the elbow can be reduced by the above countermeasure. But the causes of other noises could not be specified. The peak noise of other is thought to be the noise generated from the shaft vibration because of the peak concerned integer multiple of the fundamental frequency 40Hz of the shaft.

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APPENDIX A

Deriving of Eq.(6)

The acoustic intensity is defined as follows [3].

$$I = \lim_{T \to \infty} \frac{1}{2\pi\Delta\tau} \int_{-T/2}^{T/2} \frac{P_x(t) + \rho\omega}{\Delta\tau} \int_{-\infty}^{\infty} [p_x(t) - p_x(\tau)] d\tau d\omega$$

(A-1)

The blanket $P_x(\tau)$ becomes as follows.

$$\int_{-\infty}^{\infty} [p_x(t) - p_x(\tau)] d\tau = P_x(t) - P_x(t) - a + b$$

Where $a$ and $b$ are $P_x(-\infty)$ and $P_x(\infty)$, respectively.

Substituting Eq.(A-2) to Eq.(A-1) we obtained the next equation.

$$I = \lim_{T \to \infty} \frac{1}{2\pi\Delta\tau} \int_{-T/2}^{T/2} \frac{P_x(t) + P_x(\tau)}{\Delta\tau} [P_x(t) - P_x(\tau) - a + b] d\tau$$

(A-3)

The autocorrelation function and the cross-correlation function are given as follows [1]-[2].

$$R(t) = \int_{-\infty}^{\infty} P_x(t) \cdot P_x(t + \tau) d\tau$$

(A-4)

$$R_{12}(\tau) = \int_{-\infty}^{\infty} P_x(t) \cdot P_x(t + \tau) d\tau$$

(A-5)

And the relationship of transform pair exists between the correlation function and the spectrum.

$$G(\omega) = \int_{-\infty}^{\infty} R(t) e^{-j\omega t} d\tau$$

(A-6)

$$G(\omega) = \int_{-\infty}^{\infty} G(\omega) e^{j\omega t} d\omega$$

(A-6')

$$G_{12}(\omega) = \int_{-\infty}^{\infty} R_{12}(\tau) e^{-j\omega \tau} d\tau$$

(A-7)

$$R_{12}(\tau) = \int_{-\infty}^{\infty} G_{12}(\omega) e^{j\omega \tau} d\omega$$

(A-7')

Rewriting Eq.(A-3) we obtained the next equation.

$$I = \frac{1}{2\pi\Delta\tau} \lim_{T \to \infty} \frac{1}{2} \int_{-T/2}^{T/2} [p_x(t) + P_x(\tau)] [P_x(t) - P_x(\tau) - a + b] d\tau$$

(A-8)

Expanding the inner part of integral

$$p_x(t) + P_x(\tau) - p_x(\tau) - P_x(t) = P_x(t) - P_x(\tau)$$

(A-9)

The integral of each term can be described as follows.

$$\lim_{T \to \infty} \frac{1}{2} \int_{-T/2}^{T/2} p_x(t) P_x(\tau) d\tau = \int_{-\infty}^{\infty} p_x(t) P_x(\tau) d\tau = R_{12}(\tau)$$

(A-10)

Then Eq.(A-8) can be expressed as follows.
\[
\frac{1}{2\rho \Delta r} \left\{ R_{12}(0) + R_2(0) - R_1(0) - R_{21}(0) \right\} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} p_1(t' + \tau)p_2(t')d\tau d\tau e^{-j\omega \tau}d\tau
\]
\[
= \int_{-\infty}^{\infty} R_{21}(\tau) e^{-j\omega \tau}d\tau = G_{21}(\omega)
\]

**APPENDIX B**

**Deriving of Eq.(A-14)**

\[
G_{12}(\omega) = \frac{1}{2\rho \Delta r} \int_{-\infty}^{\infty} G_{21}(\omega) d\omega - \int_{-\infty}^{\infty} G_{1}(\omega) d\omega
\]

Taking into account the nature of the cross-spectrum as shown below,

\[
G_{12}(-\omega) = G_{21}(\omega)
\]
\[
G_{12}(-\omega) = G_{12}^*(\omega)
\]
\[
G_{12}(\omega) = G_{21}(\omega)
\]

Eq.(A-12) can be obtained as follows.

\[
l = \frac{1}{2\rho \omega \Delta r} \left\{ \int_{-\infty}^{\infty} G_{21}(\omega)d\omega - \int_{-\infty}^{\infty} G_{1}(\omega)d\omega \right\}
\]

We can replace the integral \(1/j\omega\)

\[
\frac{1}{2\rho \omega \Delta r} \left[ \Re(G_{21}) - j\Im(G_{21}) - \Re(G_{21}) - j\Im(G_{21}) \right]
\]

\[
= 2\frac{-1}{2\rho \omega \Delta r} j\Im(G_{21}) = \frac{-1}{\rho \omega \Delta r} \Im(G_{21})
\]

Therefore

\[
l = \int_{-\infty}^{\infty} \frac{-1}{\rho \omega \Delta r} \Im(G_{21})d\omega
\]