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The Effect of Pressure-Inducing System of Transducers of Dynamic Pressure Measurement

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THE EFFECT OF PRESSURE-INDUCTING SYSTEM OF TRANSDUCERS ON DYNAMIC PRESSURE MEASUREMENT

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ABSTRACT

In this paper, we will first introduce the methods and instrument of the indicated diagram of microcomputer testing compressor, and then we will emphasize the building of mathematical models of pressure-inducting system of the pressure transducer. Based on the analysis of frequency response, we will discuss how to reduce the distrubance. We hope our exploration may be helpful to those who are researching or applying the system of dynamic pressure measurement.

INTRODUCTION

Indicated diagrams are a particularly important testing-item in test on performance of reciprocating compressor. They can directly reflect the thermodynamic process of the machine, working behaviour of the valves, and operating mode for such parts as the stuffing, piston rings, etc., to a certain extent.

In a long time, because of the imperfect measuring methods and improper operating, the indicated diagrams measured are often distorted. We always use a pressure duct to induce the medium pressure in the measured cylinder into a transducer. In this way, the pressure cavity and the pressure duct constitute a pressure-inducting system whose natural frequency actually is lower than that of the pressure transducer. As a consequence, characteristics of frequency response of the pressure-inducting system would affect the dynamic measuring results.

In recent years, Sampling and processing of dynamic data of indicated diagrams have developed towards microcomputer testing system which not only samples, stores and displays continuous pressure signals in compressor cylinder, but also calculates the data and revises its errors. The effect of the pressure-inducting system of transducer, although by using electronic watt-indicator or microcomputer testing system, brings about errors at a different extent, even make it beyond recognition. Therefore, it is obviously significant to analyze and discuss characteristics of frequency response of the pressure-inducting system of the pressure transducer; in order to suggest how to minimize the effect of the pressure-inducting system on dynamic measuring, and to make that microcomputer testing system automatically revise the errors.

THE MATHEMATICAL MODEL OF THE PRESSURE-INDUCTING SYSTEM

As shown in Fig.1, the pressure measured is inducted through the pressure duct into the pressure cavity, which constitutes the pressure-inducting system that we are to discuss. Let the measured pressure be Pi(t) and the transducer pressure be P(t).

To discuss the effect of the pressure-inducting system on dynamic measuring, we have to analyze its dynamic characteristics, so as to establish its mathematical mode.

By the principle of the aeromechanics, such as electance, similarly we may use air-resistance, air-inductance as the pressure duct's parameters, and air-capacity as that of the pressure cavity of transducer, thus

$$R = \Delta P_1/G_1 \qquad (1a)$$

$$L = \Delta P_2/\dot{G}_1 \qquad (1b)$$

$$C = \frac{1}{P}\int G_2 dt \qquad (1c)$$

so, the pressure difference ΔP between two end of R is $\Delta P_1=RG_1$; and that between L is $\Delta P_2=L\dot{G}_1$.

In this way, the puessure difference between two ends of the pressure duct is

$$P_i - P = \Delta P_1 + \Delta P_2 = RG_1 + L\dot{G}_1,$$

So the medium flow through the pressure duct is

$$G_1 = (P_i - P - L\dot{G}_1)/R$$

From expression (1c), the flow through air-capacity is given by

$$G_2 = C\dot{P},$$

Supposing that the pressure-inducting system is without leakage, it is obvious that,

$$G_1 = G_2$$

So,

$$(P_i - P - L\dot{G}_1)R = C\dot{P}.$$

Because of $\dot{G}_1 = \dot{G}_2 = C\ddot{P}$, replace it into the above expression and rerrange, we have

$$LC\ddot{P} + RC\dot{P} + P = P_i \qquad (2)$$

This is the mathematical expression of the pressure-inducting system, which is a second-order linear differential equation with constant coefficients. Expression (2) can also be rewritten as

$$L\dot{G} + RG + \frac{1}{C}\int G dt + P_i \qquad (3)$$

According to the related formula, when $l/r > 8$, then

$$R = \frac{8\eta l}{\pi r^4} \qquad (4a)$$

$$L = \frac{4l\rho}{3\pi r^2} \qquad (4b)$$

$$C = \frac{V}{\rho v^2} \qquad (4c)$$

Where V is volume of the pressure cavity (cm^3), l is length of the pressure duct (cm), r is inner radius of the pressure duct(cm), η is dynamic viscosity of the pressure medium measured (g/cm.sec), ρ is density of the medium (g/cm^3) and **v** is velocity of sound of the medium (cm/sec).

FREQUENCY RESPONSE CHARACTERISTICS OF PRESSURE-INDUCTING SYSTEM

Change expression (2) by using Laplace transformation, the transfer function of the pressure-inducting system is

$$H(s) = \frac{P(s)}{P_i(s)} = \frac{1}{LCS^2 + RCS + 1} \tag{5}$$

Let pressure in the cylinder of the measured compressor be $P_i(t) = P_i \operatorname{Sin}\omega t$, replacing S with $j\omega$, the frequency response function of the pressure-inducting system is

$$H(j\omega) = \frac{1}{1-\omega^2 LC + j\omega RC} \tag{6}$$

Stable response of the system, i.e. the pressure sened by the transducer, is

$$\begin{aligned} P(t) &= P\operatorname{Sin}(\omega t+\varphi) \\ &= P_i \left| H(j\omega) \right| \operatorname{Sin}(\omega t+\varphi) \end{aligned}$$

so, the amplitude ratio is

$$\begin{aligned} \frac{P}{P_i} &= \left| H(j\omega) \right| \\ &= \frac{1}{\sqrt{(1-\omega^2 LC)^2 + (\omega RC)^2}} \end{aligned} \tag{7}$$

and the phase difference is

$$\varphi = -tg^{-1} \frac{\omega RC}{1-\omega^2 LC} \tag{8}$$

Expressions (7) & (8) can be written as

$$\frac{P}{P_i} = \frac{1}{\sqrt{(1-(\omega/\omega_\circ)^2)^2 + 4\xi^2(\omega/\omega_\circ)^2}} \tag{9}$$

$$\varphi = -tg^{-1} \frac{2\xi(\omega/\omega_\circ)}{1-(\omega/\omega_\circ)^2} \tag{10}$$

Where $\omega_\circ$ is natural frequency of the pressure-inducting system, ξ is the damping coefficient.

$$\omega_\circ = \frac{1}{\sqrt{LC}} = \frac{\sqrt{3\pi}}{2} \frac{rv}{\sqrt{lV}} \tag{11}$$

$$\xi = \frac{1}{2}\omega_\circ RC = 2\sqrt{\frac{3}{\pi}} \frac{\eta\sqrt{lV}}{v\rho r^3} \tag{12}$$

According to expression (9) & (10). The frequency response surves of the pressure-inducting system are shown in Fig. 3 & 4.

HOW TO MINIMIZE DISTORTION OF THE INDICATED DIAGRAMS?

It is well-known that the indicated diagram is a continuous periodic function and it can be expanded in Fourier's Series, therefor, we can obtain its corresponding fundamental harmonic and limited higher one. When the compressor's speed is 350 r.p.m., its fundamental frequency is 5.83 HZ, that of its higher harmonic are 5.83xn (n=2,3,4,......), the pass band of the testing system at least ranges from 5.83 to 117 HZ. Even if $\omega/\omega_0 \ll 1$, P is not yet equal to P_i, φ is not zero, i.e. the errors of stable response always exist. Therefor, when compressor's speed is given, the influence of the pressure-inducting system on dynamic measuring can be reduced so long as we increase its natural frequency.

From expression (9),(10) & (11), we can come to the conclusions that, when the measured medium is given, P/P_i and φ are dependent on compressoe's speed, and ω_0 do on l, r and V. Fig. 5a is the indicated diagrams measured and recorded according to different length of the pressure duct. From this, we know that the longer the pressure duct, the lower the natural frequency of the pressure-inducting system is, and the lower the addional harmonic frequency is, the larger the amplitude is. Thus, the curves of the indicated diagrams without the pressure-inducting system are more smooth because there is no additional higher harmonic.

When higher harmonic is 87.5 HZ ($\omega = 15 \times 5.83$), the dynamic errors of the pressure duct with different length are shown in table 1.

Table 1

Duct (cm)	r (cm)	V $(cm)^3$	ω (HZ)	ω_0 (HZ)	ξ	φ (angle)	P/P_i	errors
28	0.4	33.1	87.5	686	41.8×10^{-4}	-0.063	1.017	1.7%
43	0.4	33.1	87.5	554	51.8×10^{-4}	-0.096	1.026	2.6%
58	0.4	33.1	87.5	477	60.2×10^{-4}	-0.131	1.035	3.5%

Obviously, by minimizing volume V of transducer's pressure cavity,increasing inner radius r of the pressure duct or shortening length l of the pressure duct, we can raise the natural frequency of the pressure-inducting system. This is why the pressure cavity is not designed on the transducer for dynamic pressure measuring and it is necessary to level the pressure capsul with the measured pressure side in measuring and installing.

On using microcomputer to test compressor's indicating diagrams, such kind of problem is encountered, e.g. at the instant when the discharge valve is opend at the end of compression process of the compressor and when the suction valve is opend in finishing the expansion, there is a pressure jump for the pressure-inducting system, and strong pressure disturbance is produced. When the limiting frequency of the measuring system is lower than the highest one of the measured signals, the output of the measuring system can not catch up with the measured input signals, thus producing greater dynamic errors.

However, we can make use of microcoputer as a advancing revision link in measuring system to broaden the frequency band of the measuring system, thereby meet the requirements with the limiting frequency in the measuring system is higher than that of the measured signal. Fig. 5b & 6b are waveforms of the indicated diagrams through FIR digital fiter's processing. It basically eliminated the dynamic errors from the different pressure-inducting systems, the block diagrams when the digital tiliter applied onto the microcomputer system are shown in Fig.2. This measuring system is particularly efficient for the multi-point dynamic measuring system of compressor.

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(3) Chang, K. Y. , Kerr, S. V. , MacLaren, J. F. T. , a Versatile Microcomputer Controlled High Speed Data Acquisition System Applied to Compressor, Proc. 6th Purdue Compressor Technology Conference, 1982.

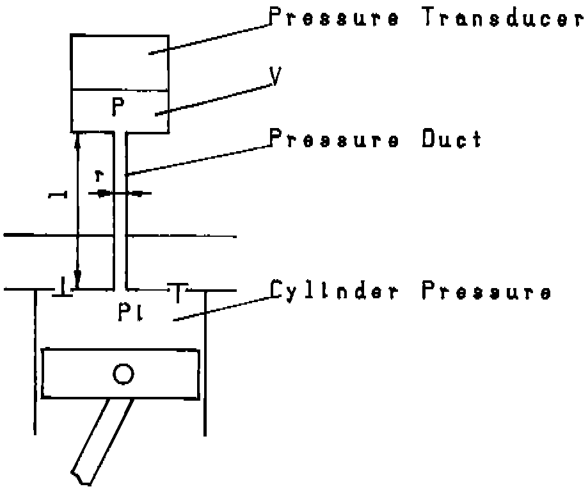

Fig. 1: Diagram of the Pressure-inducting System

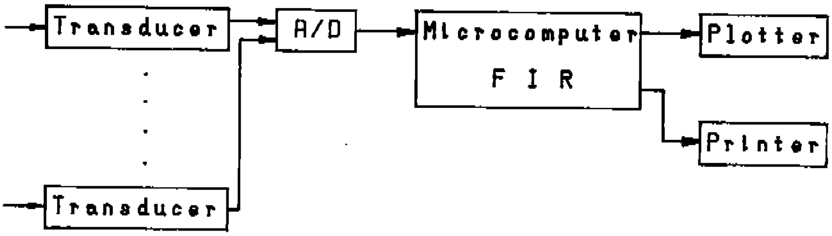

Fig. 2: Measuring System with Digital Filter

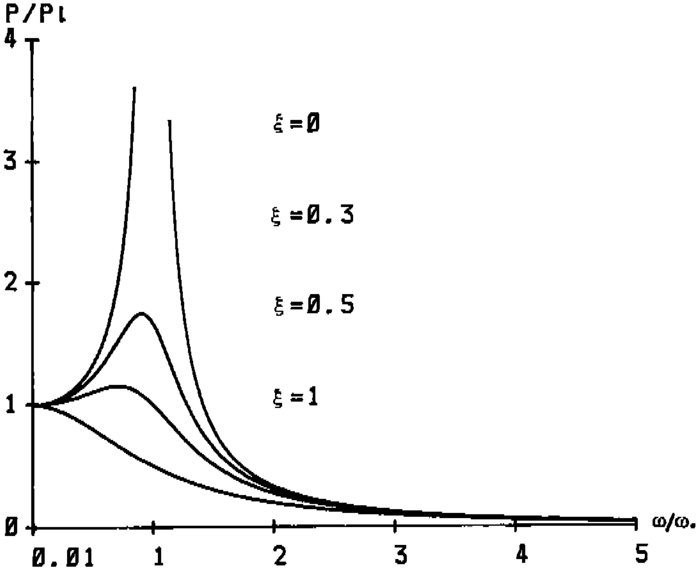

Fig. 3: Amplitude-frequency Characteristic of the Pressure-inducting System

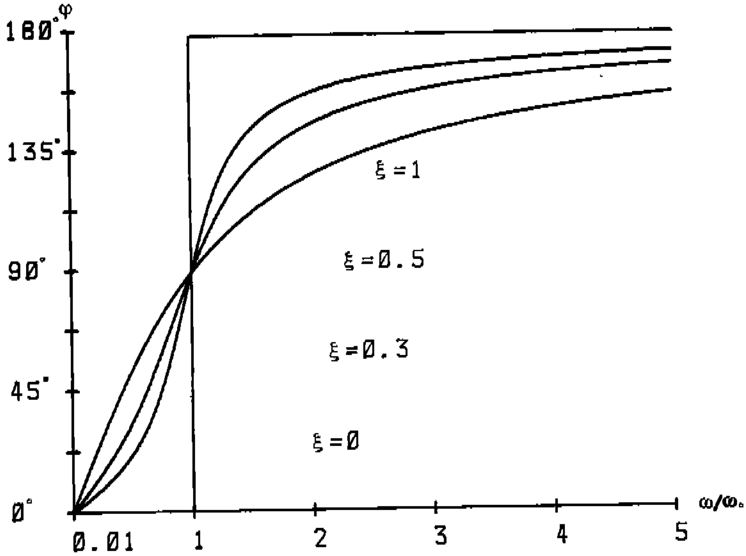

Fig. 4: Phase-frequency Characteristic of the Pressure-inducting System

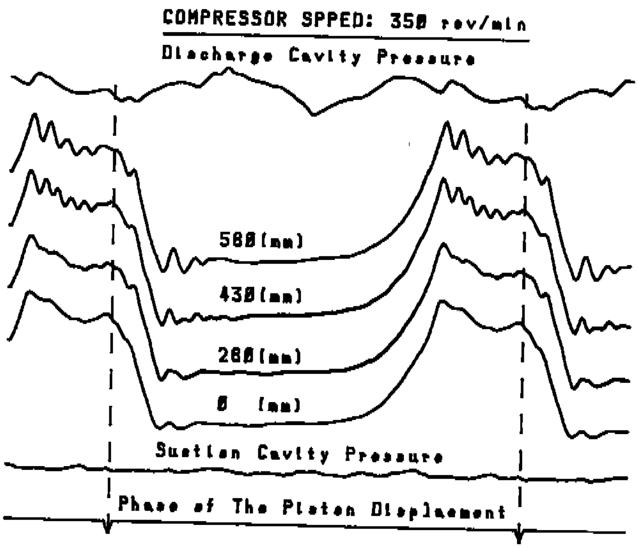

Fig. 5a: P-α Curves for Different Lengths of the Pressure Duct

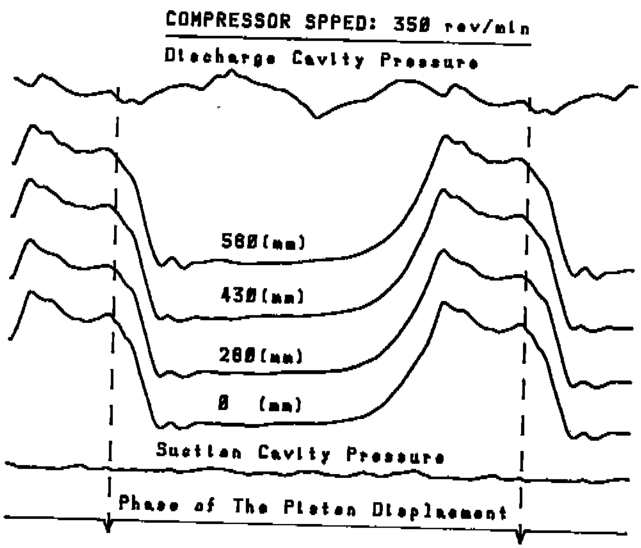

Fig. 5b: P-α Curves through FIR Filter's Processing

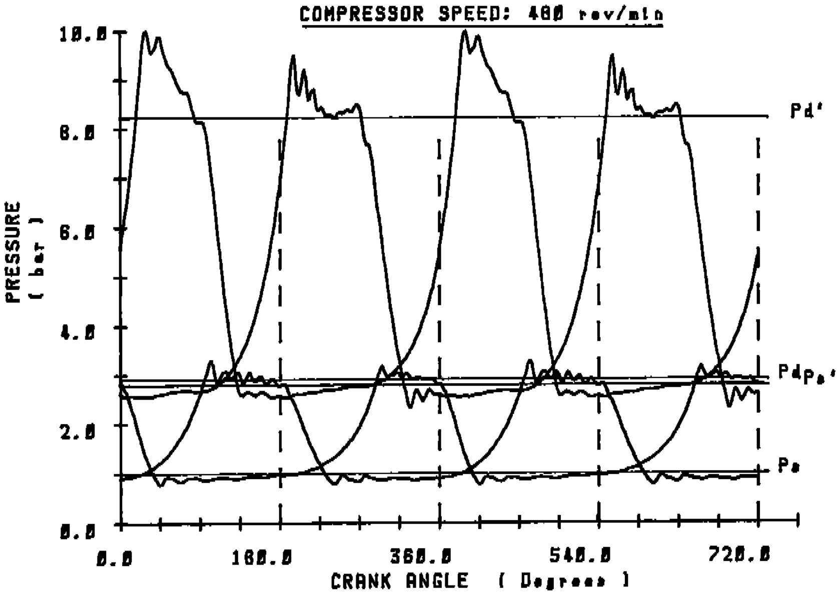

Fig. 6a: P-α Curves for Type 3L-10/8 Compressor

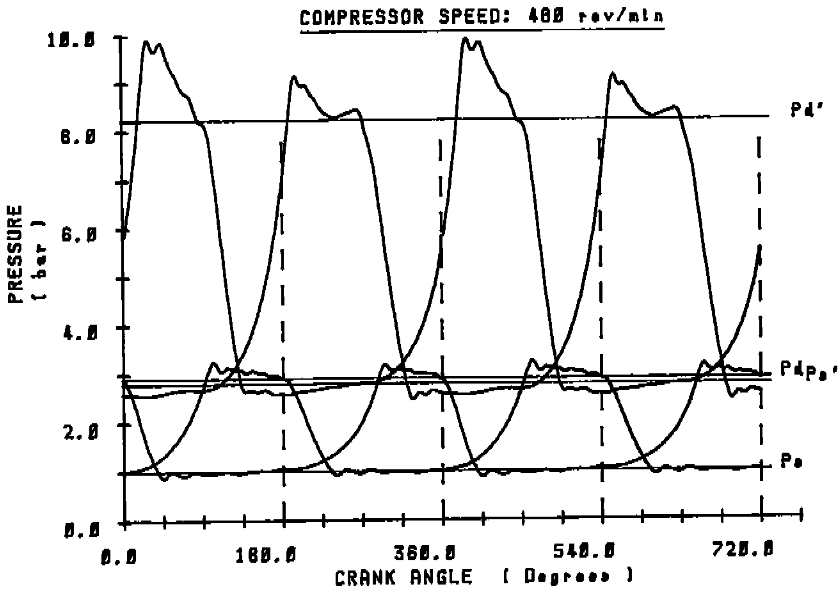

Fig. 6b: P-α Curves through FIR Filter's Processing