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D. Wu

Q. Pan

X. Sheng

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THE APPLICATION OF A MICROCOMPUTER IN EXPERIMENT OF RECIPROCATING COMPRESSORS

Wu Danqing, Pan Qi
Department of Chemistry and Chemical Engineering
Xi'an Jiao Tong University, China

Sheng Xiangxing
Department of Automation
Wuhan Chemical Engineering Institute, China

ABSTRACT

To analyse the modern high speed reciprocating compressors, a microcomputer controlled system has been developed which govered the acquisition, storage, processing and display of experimental data from the testing machine. A trigger pulse from a clock started the data acquisition programs, signals of pressure in the cylinders and valve plenums and of displacement of valves were acquired by transducers, amplifiers, and an analog-digital converter, the data were stored in cartridge discs. The stored data were precessed and displayed in digital form or in graphical form on the visual display unit. Pressure inside the cylinders could be recorded by a graph plotter not only in the form of conventional open type P-α traces, but also in the form of close type P-V graph. By using the new system, the indicated power Ni, the power dissipations of suction and discharge Ns and Nd, the process index of compression n, and the cylinder availability factors λv and λp of the sample machines were figured out exactly.

The new system has been used in experimental analysis of three air compressors, and the results were very satisfactory. It provids the optimum design of compressors with update reference data and the mathematic modeling of compressors with suitable experiment methods.

SYMBOLS

n polytropic compression process index

Ni indicated power of the stage

Ns	suction power dissipation
Nd	discharge power dissipation
λv	cylinder availability factor of volume
λp	cylinder availability factor of pressure
α	crankangle
L	length of link rod
R	radius of crankshaft
D	diameter of cylinder
V	volume of cylinder
Ps	nominal suction pressure
Pd	nominal disharge pressure

INTRODUCTION

It has been more than 20 years that computers were used in design and manufacture of compressors[1]. It needed computers to build mathematic models which simulate compressors. It also needs computers to develop a computer cotrolled system for the acquisition and processing of experimental data from compressors which provids accurate results in order to assess the validity of the predictions made by the models [2]. According to thermodynamics, **френкель.М.И** [3] developed engineering design theories and presented analytic calculating methods and values of related thermal parameters of compressors. These parameters were obtained by studying low speed compressors with mechanical indicators in 1940's and 1950's. It proved to have great inherent error to apply the conventional methods and parameters to modern high speed compressors. It was well known that electronic indicators, such as cathode ray oscilloscope (CRO) and multi-channel ultra-violet-(UV) recorder could not obtain accurate experimental data of thermal parameters either. A new system must be sought which would (a), avoil the several well known limitations of a CRO or UV recorder (b), provid the experimental results in either digital or graphical forms for accurate analysis of performence of the machine and (c), record the P-V graph and figure out thermal parameters (n, Ni, Ns, Nd, λv, λp) of the testing compressor.

THE NEW SYSTEM

The new system consists of transducers for pressure, valve displacement, and top dead center, signal amplifiers, mitiplexers, analog-digital converter (AI13), an Apple-II microcomputer with its peripherals and related software. The maximum processing rate of the analog-digital converter is 50000 readings per second.

The mean pressures and the pressure pulses in the testing system were picked up by BPR-2 pressure transducers, and valve displacements by non-contact inductive transducers. The piston dead center signals were sensed by selfmade photoelectric transducer which produces a square wave signal at top dead center. Analog signals from transducers were passed via the amplifiers, multiplexers and the A/D converter to the microcomputer. A schematic diagram of the hardware is shown in Figure 1.

The aquisition start point and duration were determined by a controlling acquisition duration sub-program which were written in Assembler language. The start point was Top Dead Center (TDC) and the acquisition duration was such a time interval that in which the testing machine finished a working cycle. When beginning the experiment, first, the main program were read into the inner memory of the computer from the cartridge disc unit, after the compressor had reached stable operating conditions, the controlling duration sub-program was executed which would determine exactly the start point (TDC) and the time interval T (acquisition duration). Then the microcomputer modified automatically the acquisition duration in the acquisition sub-program, sent swicth-controlling signals via D/A converter, and transferred the dead center signal to out-trigger pulse unit. After the out-trigger pulse had started the acquisition sub-program, the microcomputer opened each channel sequentially, so that the pressure in cylinders and suction and discharge plenum chembers and valve displacements were sensed, converted, and sent to the computer inner memory, or, the acquisited datc could be stored in the cartridge disc for permanent conservation by executing the storage sub-program. Then the date were filtered and calibrated by some sub-programs. The testing results could be displayed on the screen and recorded either by graph plotter or by teletypewriter.

TREATMENT OF THE EXPERIMENTAL DATA

The signals from transducers often were accompanied with random noise. The noise affects the accuricy of processed data and even results in some mistakes. In order to reduce the noise, separate the component from basic frequency, and smooth the distribution of the recorded data, the data filter technology had to be used. Generally speaking, the recorded time series $x(t)$ are sum of true signals $P(t)$ and accompanied noise $n(t)$:

$$x(t)=P(t)+n(t) \qquad (1)$$

if the average of $n(t)$ was zero and the self-related function of the random singnals were $Rn(\tau)$, while $P(t)$ are true signals, then the mathematic expection of $x(t)$ would be:

$$E\{x(t)\}=P(t) \qquad (2)$$

while

$$\sigma^2=E\{n^2(t)\}=Rn(0) \qquad (3)$$

if $Rn(0)$ was far smaller than the root-mean square of $P(t)$, the noise effect could be neglected, and $x(t)$ could be used to evaluated $P(t)$. However, if $Rn(0)$ and $P(t)$ were in same quantitative level, $x(t)$ could not be used to evaluated $P(t)$, in this case, the data filter technology had to be used to reduce the noise effect. While processing the data, the group shifting arithmatic mean method was used.

The processed data needed to be calibrated. Pressure calibration was carried out in the dynamic calibration method. Two pressure calibration tanks were used which connect the suction and discharge plenum chambers of the compressor respectively. The tanks were connected to the pressure transducer to be calibrated by a computer controlled three-way spiral valve. After acquisiting the nominal suction and discharge pressure, the calibration coefficient was figured out, then the coefficient was multiplied by numarical quantities of measured pressure signals, the cylinder pressure and plenum pressure were obtained. The valve displacement calibration used the relitive calibration method. Figure 2 shows the traces of a 2V-0.6/7 air compressor which were recorded by the graph plotter.

P-V GRAPH AND THERMAL PARAMETERS

Theoratically, it is easy to convert the open type p-α traces into P-V graph, with substituting the corresponding cylinder working volume V for the crankangle α. However, the accurate result of this substitution could be obtained with the help of software of the microcomputer. At an optional α, the piston displacement off TDC is:

$$x=L[1-\sqrt{1-\lambda^2\sin^2\alpha}+\lambda(1-\cos\alpha)] \qquad (4)$$

here $\lambda=R/L$
correspondence with the displacement x, the cylinder volume V is:

$$V=\frac{\pi}{4}D^2\cdot L\left[1-\sqrt{1-\lambda^2\sin^2\alpha}+\lambda(1-\cos\alpha)\right] \qquad (5)$$

With a sub-program which converted the abscissa α into V and made the P-V graph smooth, the graph plotter has recorded a group of performance traces of a testing machine, 2V-0.6/7 air compressor shown as Figure 3, which included the close type P-V graph, pressure pulsations in suction and discharge plenums, and valve displacements.

Figure 4 shows different P-V graphs with varied compression ratio of the testing machine, with changing the backpressure of discharge pipe.

Figure 5 shows the effect of changing cooling conditions on the P-V graph.

Schema for analyzing and calculating P-V graph is shown in Figure 6. The indicated power of the stage during a cycle is the enclosed area a12b34ca, the shaded areas under Ps and over Pd stand for the power dissipation of suction and discharge respectively. Ni, Ns and Nd can be obtained from numerical integration of the measured data. Cylinder availability factor of volume:

$$\lambda_V=V_s'/V_h \qquad (6)$$

and cylinder availability factor of pressure:

$$\lambda_p=V_s''/V_s' \qquad (7)$$

can also be obtainded from integration of processed data. In this case, the key technology was to determine exactly the intersection points between nominal pressure Ps, Pd and dynamic pressure P, i.e., the location of 1, 2, 3, and 4.

The constant polytropic compression process index was determined by equi-work method as follow. The work consumed during the process 1-2 is the enclosed area 1235641, denoted by W12, which could be calculated by numerical intergration. From thermodynamics,

$$W12=\frac{n}{n-1}P_1V_1\left[(Pd/Ps)^{\frac{n-1}{n}}-1\right] \qquad (8)$$

only n is unknown in the equation above, using mathematic iteration, the constant compression process index would be obtained, which was substituted for real process index.

Table 1 shows the processed parameters of the air cooled 2V-0.6/7 compressor.

Table 1 Thermal Parameters of 2V-0.6/7 Compressor (n=1200 r.p.m.)

pressure ratio	Ni (kw)	Ns (kw)	Nd (kw)	$\frac{Ns+Nd}{Ni}$	n	λv	λp
8	1.636	.075	.11	.113	1.474	.753	.865
7	1.61	.082	.1	.113	1.543	.793	.864
6	1.548	.079	.099	.114	1.572	.816	.869
5	1.444	.111	.096	.143	1.651	.852	.869
4	1.289	.105	.093	.153	1.718	.885	.868

It can be found out from Table 1 that a), with the decrease of pressure ratio, suction and discharge relative power dissipation, compression index n and volumetric factor increase; b), the value of both λ_v and λ_p in Table 1 are smaller than those mentioned in [3] and the polytropic compression process indexes are not only different from those in [3] , but also all greater than the adiabatic index of air k (k=1.4 for air). The reason for this may be the high running speed of the compressor and the limited cylinder size. Because of the poor cooling condition, friction heat inside the cylinders during compression process could not be taken away by coolant, it heats the compressed air and made the index n greater than k. So, the compression process needed more mechanical work.

Table 2 shows processed thermal parameters of a water cooled one-cylinder low speed air compressor. From Figure 5 and Table 2, it can be seen that when inlet water temperature rises, the compression curve on the P-V graph steepens and the indicated power Ni and compression index n increase. When the temperature is less than 30°C, the index less than 1.4.

The thermal parameters of a two stage water cooled L2-10/8 air compressor has been treated with this system and the results are shown in Table 3.

Table 2 Thermal Parameters of One-cylinder Water Cooled Compressor (n=260 r.p.m.)

inlet tem. of cooling water t(°C)	Ni (kw)	Ns (kw)	Nd (kw)	$\frac{Ns+Nd}{Ni}$	n	λv	λp
15	1.532	0.099	0.101	0.131	1.327	0.882	0.898
30	1.645	0.101	0.121	0.135	1.392	0.894	0.902
50	1.707	0.103	0.134	0.139	1.43	0.907	0.898

Table 3 Thermal Parameters of Two-stage Water Cooled Compressor (n=980 r.p.m.)

Stage	Pressure ratio Pd/Ps	Ni (kw)	Ns (kw)	Nd (kw)	$\frac{Ns+Nd}{Ni}$	n	λv	λp
1	2.8	14.54	0.985	0.753	0.119	1.405	0.866	0.979
2	2.85	13.91	0.688	0.751	0.109	1.238	0.811	0.985

CONCLUSIONS

1. The microcomputer with disc storage unit and high speed A/D converter provids a convenient and accurate system for data acquisition, processing and recording of performance experiment of compressors. The output of the system can be either digital or graphical form.

2. The high accuracy experimental data processed with this system have great help to the development and revision of mathematic model of compressors.

3. With software technology, the p-α traces acquisited can be converted into enclosed P-V graph, meanwhile, more accurate thermal parameters can be obtained, which simplifies the experimental data treatment greatly and provids useful parameters for modern compressor design.

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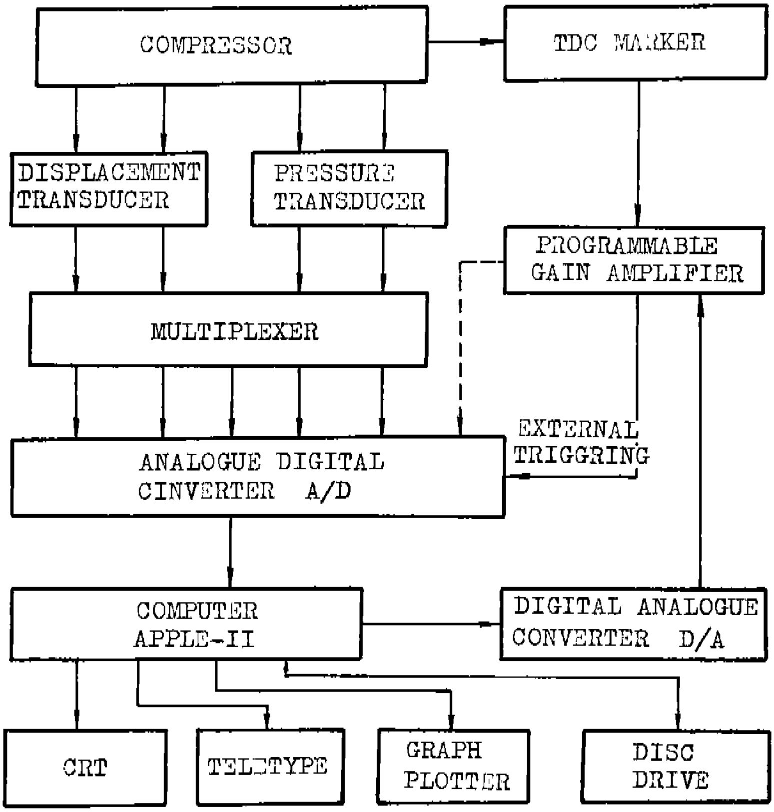

Fig. 1: Hardware Configuration for Data Acquisition System

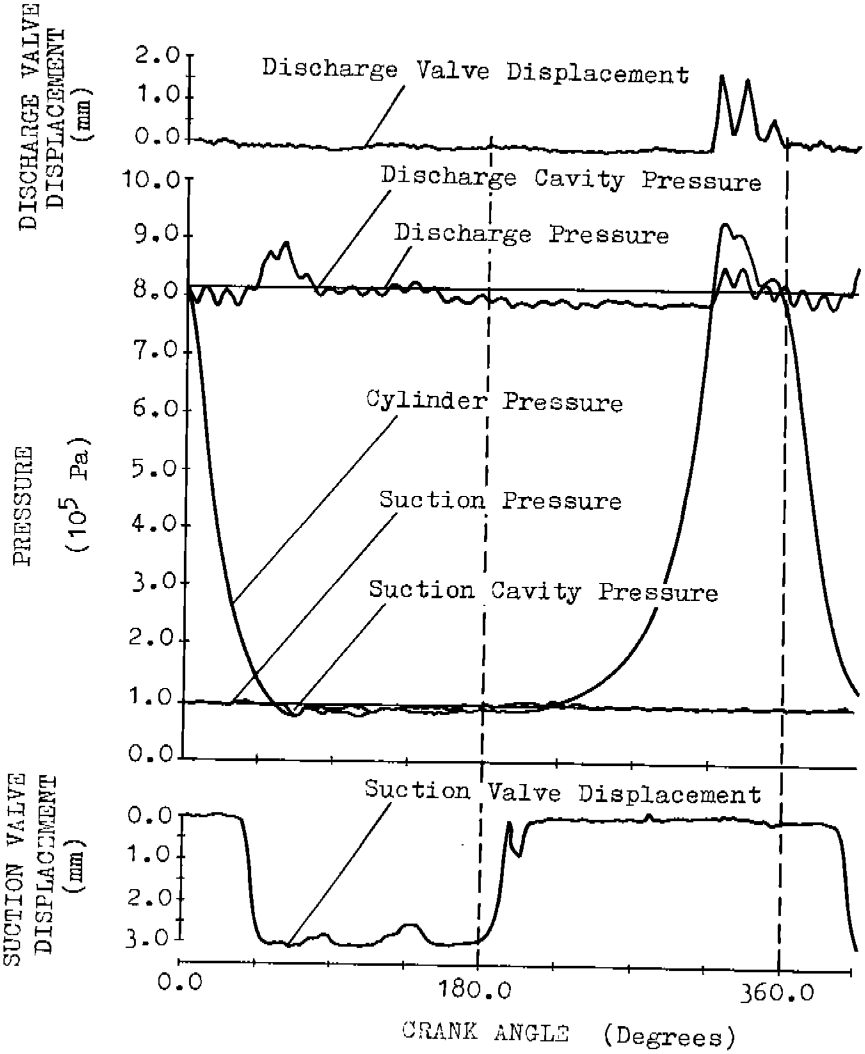

Fig. 2: Experimental Results of 2V-0.6/7 air Compressor (P-α Graph)

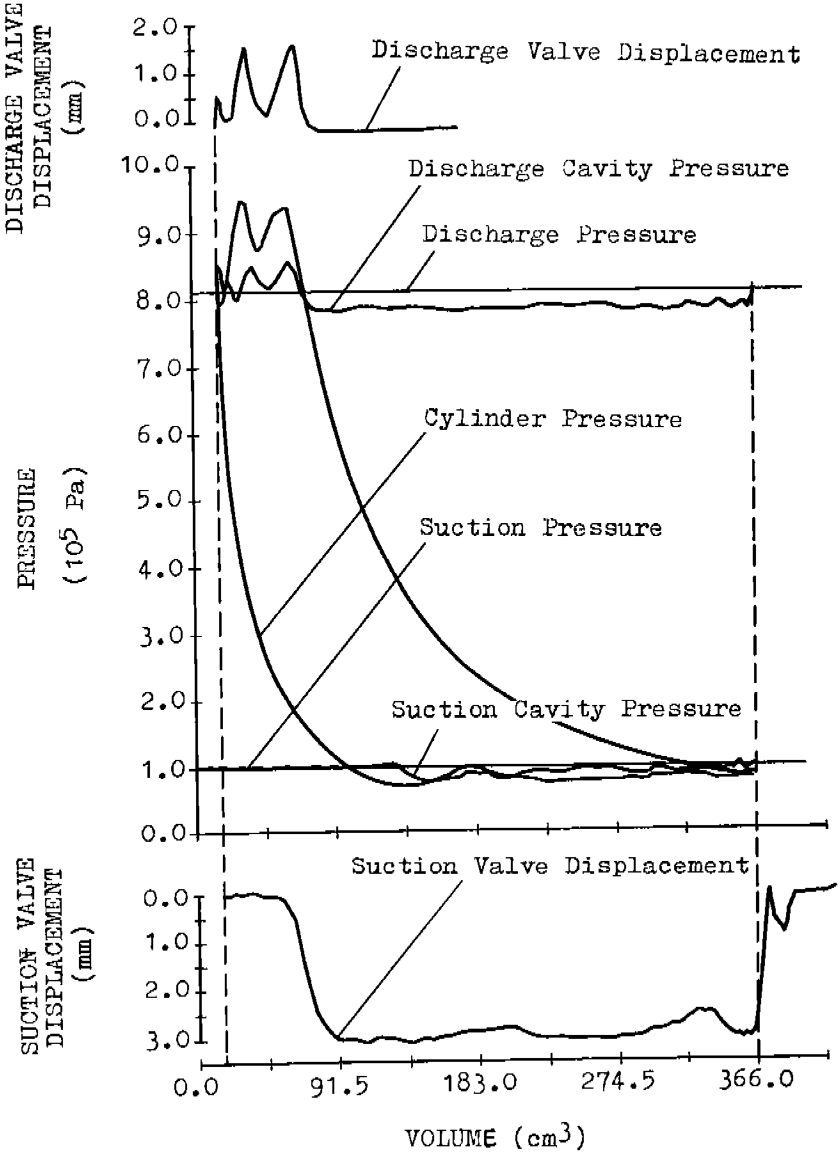

Fig. 3: Experimental Results of 2V-0.6/7 air Compressor (P-V Graph)

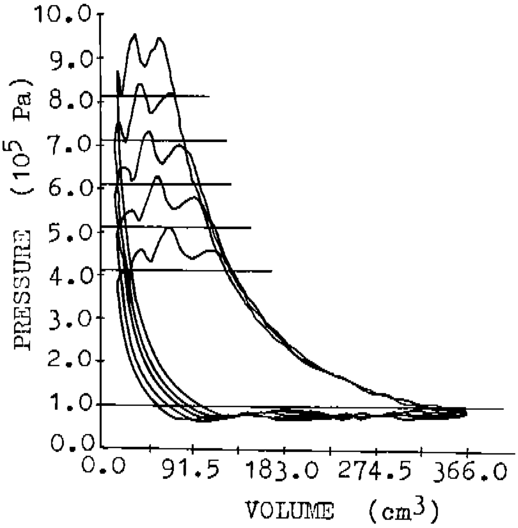

Fig. 4: P-V Graph with Pressure Ratio Change of 2V-0.6/7 air Comp.

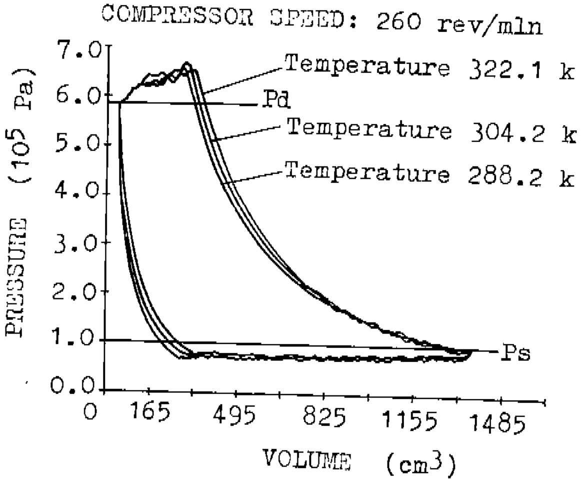

Fig. 5: P-V Graph with Cooling Condition Change

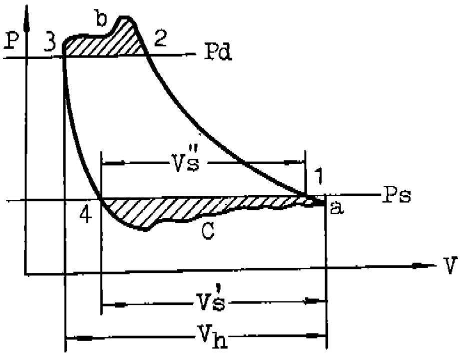

Fig. 6: Schema for Analyzing of P-V Graph