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# Improvement of Performance for Superhigh Pressure Diaphragm Compressor

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# IMPROVEMENT OF PERFORMANCE FOR SUPERHIGH PRESSURE DIAPHRAGM COMPRESSOR

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## ABSTRACT

The service life of the diaphragm on the diaphragm compressor is affected to a large extent by the liquid-gas pressure differetial across the diaphragm. When the differential goes overhigh, it will lead to the damage of diaphragm. This problem is especially severe for superhigh pressure diaphragm compressor. The present article introduces a new type of automatic pressure regulating valve for superhigh pressure diaphragm compressor. This valve can keep the liquid pressure under the diaphragm going up and down along with the increasing and decreasing of the compressor discharge pressure. Meanwhile it can maintain the liquid pressure slightly higher than the gas pressure so as to minimize the destruction caused by the excessive liquid-gas pressure differetial.

## INTRODUCTION

In recent years, metal diaphragm compressor has been used in more fields due to its superiorities, such as no leakage, no contamination to the process gas and high single stage compression ratio which makes it easier to attain superhigh pressure compression. But it has been a sticky problem to prolong the service life of metallic diaphragm, especially for superhigh pressure diaphragm compressor, for which the current diaphragm's service life is normally sveral hundred hours.

Studying carefully, we found out that the main factors causing the damage of diaphragm come from primarily two aspects. One is the deformation stress on diaphragm, the other is the additional local stress generated by the liquid-gas pressure differential on the diaphragm at the mouthes of process gas inlet and outlet. For the first one, the destructive stress can now be reduced to fairely weak by means of optimizing the cavity plotting and improving the manufacturing quality of the cavity surface. However, the second one, additional local stress is difficult to be eliminated.

The additional local stress, acting on the diaphragm at the mouthes of process gas inlet and outlet, is generally considered as a shearing stress which primarily depends on the liquid-gas pressure differential across the diaphragm. While the pressure differential is affected by the liquid pressure limiting valve on the compressor and the working procedure of compressor.

At present, most of the liquid pressure limiting valves for diaphragm compressor are spring-loaded type, which is similar to a safty valve having only one limiting pressure for opening. But in actual running, the compressor discharge pressure is variable. So there will be a high pressure differential between liquid and gas across the diaphragm.

Being limited by its small discharge capacity, diaphragm compressor is usually used for cylinder filling. When the pressure in vessel reaches the desired value, the compressor will stop running, i.e. the discharge pressure undergoes an up and down procedure without staying at a high level for a long period. Thereby, we can see that the liquid-gas pressure differential is large before and after the discharge pressure reaches the designed max. value. It is the main factor to damaged the diaphragm.

Let's take GME120 type diaphragm compressor, designed by GME (China National General Machinery Engineering Corp.) in early years, as an example (whose max. discharge pressure is 120 MPa, i.e.17400 psi) It works with a spring type pressure limiting valve, for which the opening pressure is set at 130 MPa (18850 psi) according to its max. designed discharge pressure. See Fig.1, when the compressor starts, the liquid-gas pressure differential is nearly 115 MPa (16675 psi).

In order to prolong the service life of diaphragm, GME used to install a manual pressure control valve on superhigh pressure diaphragm compressor to control the liquid pressure going up and down along with the gas pressure. The results are that, the liquid-gas pressure differential is reduced greatly and the service life of diaphragm is increased to some extent, but its shortcoming is obvious that the operator is too near to the machine to be safeguarded.

If taking compressor discharge pressure (almost the same as the gas pressure above diaphragm) as a limiting means instead of manual control to control the opening pressure (i.e. the peak value of liquid pressure under diaphragm) of the pressure limiting valve, it would be the optimum pattern to attain automatic regulating for liquid-gas pressure differential across the diaphragm. Many efforts have been made for that purpose and several kinds of valves designed with the above mentioned principle are available such as diaphragm type automatic pressure regulating valve and overflow type automatic pressure regulating valve. Unfortunately, they are not suitable for superhigh pressure diaphragm compressor.

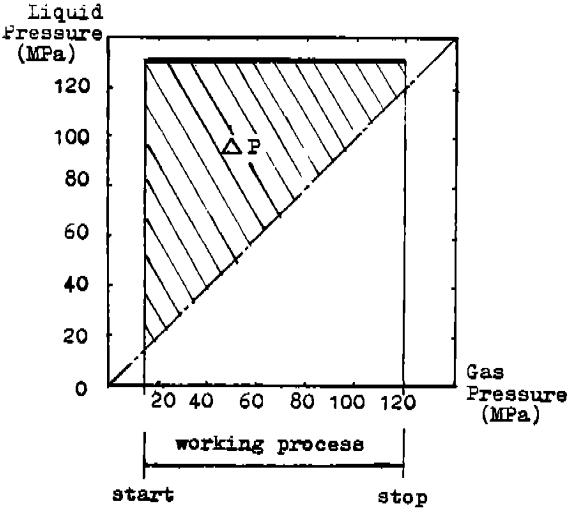



**Fig.1 Liquid-gas Pressure Curve Of GME120 Diaphragm Compressor**

COURSE OF IMPROVEMENT

We set out to develop GME200 diaphragm compressor with a higher discharge pressure in 1984.

The main parameters are as follows:

| | |
|---|---|
| max. discharge pressure: | 200 MPa ( 29000 psi ) |
| stroke capacity: | 0.453 $m^3/h$ ( 16 cft/h ) |
| gas: | hydrogen H2 |
| usage: | fill superhigh pressure vessel |

The objective of this improvement is to develop an automatic pressure regulating valve adapted to hydrogen and discharge pressure of 200 MPa (29000psi) and in the same time to minimize diaphragm damage caused by liquid-gas pressure differential.

The train of thought we followed in the design is as follows: a normally-closed valve needle is set in the automatic pressure regulating valve, the rear of which (i.e. valve rod) extends into a pneumatic chamber communicating with the compressor discharge pressure. Thus the liquid pressure in front of the valve needle will reach equilibrium with the gas pressure behind the valve needle while pushing against each other. When the liquid pressure is higher than the gas pressure, the valve needle will open and hydraulic fluid will be released. As the liquid pressure goes down, the gas pressure will push valve needle to close in time.

There are two difficulties to be dealt with in realizing the above train of thought.

First, there is 200 MPa (29000 psi) high pressure hydrogen, a high permeable medium, in the pneumatic chamber at rear of valve rod. It's required to seal the hydrogen absolutely that no leakage is allowed. In the same time, the valve rod must be highly sensitive to gas pressure and could move nimbly. It is a problem of motional sealing for superhigh pressure gas.

Testing with packing gland of different constructions on GME120 diaphragm compressor, we found out that when the sealing for pressure of 120 MPa (17400 psi) was effective, the valve rod would be held by the great clamping friction force and could not move smoothly. Vice versa, if the valve rod could move smoothly while the packing gland would give up the function.

The other difficulty is the complicated working conditions of the hydraulic fluid at the valve seat opening. It is difficult to calculate theoretically. The main factors are: in the superhigh pressure state, the viscosity and compressibility of hydraulic fluid change greatly, and also the working frequency of diaphragm compressor is very high, normally up to 400 rpm.

We have designed various types of automatic pressure regulating valve and tested each of them with GME120 compressor repeatedly. We accumulated a wealth of experience with a large number of test data from failures. Later on, we created the liquid-gas converting construction, which, putting an end to all, is a substansive success in developing the automatic pressure regulating valve. In 1986, the automatic pressure regulating valve passed the test running with GME120 diaphragm dompressor.

In 1988, GME brought forth GME200 diaphragm compressor with the new automatic pressure regulating valve. It is a superhigh pressure diaphragm compressor capable of self-controlling through liquid-gas pressure differential.

Fig.2 is the photograph of the compressor. Fig.3 ahows the schematic layout of its construction.

The performance of this type of diaphragm compressor reaches the design requirement. The rotary speed is 350 rpm. 'A' is the automatic pressure regulating valve, whose front opening is connected to the hydraulic fluid chamber under the diaphragm and the rear opening is interlinked with the compressor discharge pipe by the gas pressure feedback pipe 'B'. The released liquid is led to the crank case by pipe 'C'. The lubricant is conveyed to the rear part of the pressure regulating valve through pipe 'D'.

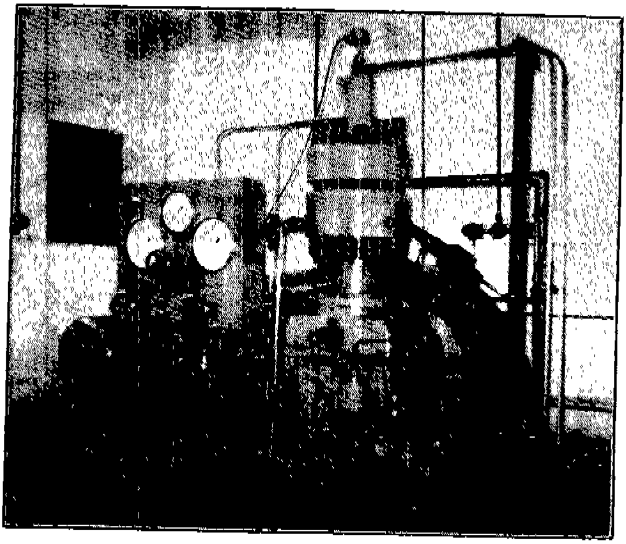


Fig.2 Photograph Of GME200 Diaphragm Compressor

Fig.4 shows the photograph of automatic pressure regulating valve installed on GME200 diaphragm compressor. Fig.5 shows its stru structure sketch.

This type of automatic pressure regulating valve is designed with principle of liquid-gas pressure equilibrium while pushing against each other. The closing force at the valve needle comes from the pneumatic chamber at rear of valve rod and a spring.

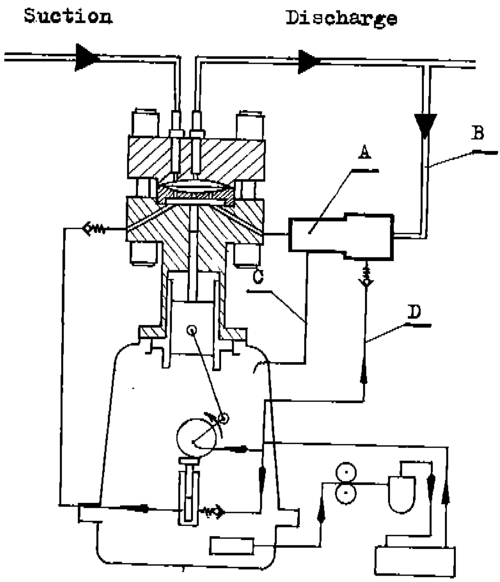



Fig.3 Schematic Layout Of Structure Of GME200 Diaphragm Compressor

There employs the pneumatic-hydraulic converting mechanism at the rear part of the valve consisting of pneumatic chamber 'G' and small hydraulic chamber 'L'. The small hydraulic chamber 'L' is hermetic. The free piston is the movable interface between it and pneumatic chamber 'G'. Once

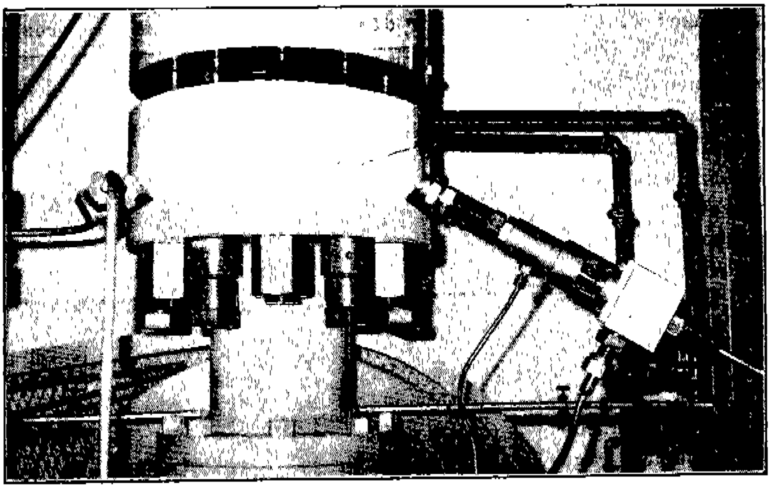
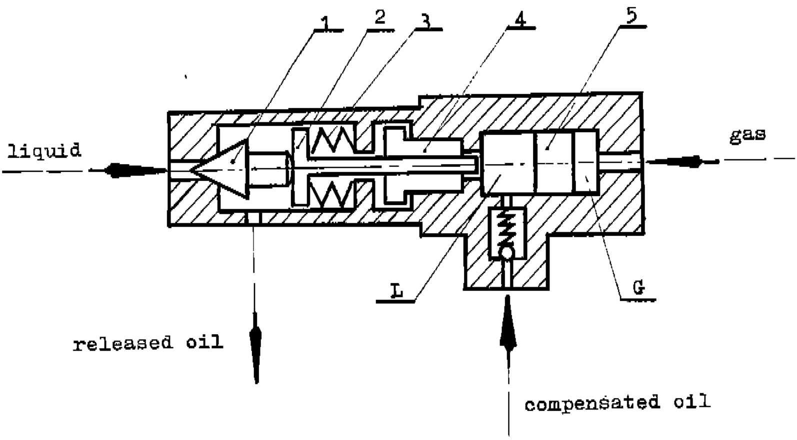


Fig.4 Photograph Of Automatic Pressure Regulating Valve On GME200 Diaphragm Compressor




1. Valve Needle; 2. Valve Rod; 3. Spring; 4. Packing Gland;
5. Free Piston.

Fig.5 Sketch Of The Construction Of The Automatic Pressure Regulating Valve

there is a pressure in pneumatic chamber 'G', the free piston will move a bit, and an exactly same liquid pressure as the gas pressure will be created in the small hydraulic chamber 'L'. Thereby, the motional sealing for gas is replaced by motional sealing for liquid at the rear of valve rod. Generally, motional sealing for liquid is easier to be attained than for gas, although it is under superhigh pressure.

Conical with wide sealing surface is adopted.

A one-way compensating valve is adopted for the small hydraulic chamber'L'. The lubricant pump on the compressor can fill oil to the small hydraulic chamber whenever the machine started, in case that there is permeation in the small hydraulic chamber.

The design performance for the automatic pressure regulating valve are as follows:

When the valve opens:

$$P1 = K\,P2 + C$$

where,
P1 —— hydraulic pressure in front of the valve needle;
P2 —— pneumatic pressure behind the valve needle;
C —— constant;
K —— coefficient.

i.e. to make the hydraulic pressure before the valve be in proportion with the pneumatic pressure behind the valve, and higher than it by a constant.

## RESULTS & CONLUSION OF THE RUNNING

Up to date, we have operated GME200 diaphragm compressor with automatic pressure regulating valve for hundreds of times for pressurization trial. For each running, we have noted down all the data strictly. A set of data recorded for one pressrization process is given in the following table, which is taken from a trial running. All the data were measured by pressure sensor. The curve shown in Fig.6 is the relations between liquid pressure and gas pressure, which is made according to the data listed in the above mentioned table.

<u>Results</u>:

a) Fig.6shows the liquid pressure changes along with the variation of the compressor discharge pressure. And the liquid-gas pressure differential across the diaphragm is kept within a range of 2.65 -- 23.8 MPa(384.25 — 3451 psi), during the whole process when the discharge pressure increses from 31.95 MPa(4632.75 psi) to 202.15 MPa(29311.75 psi).

b) By observation and checking up, we found that there was an excellant sealing effect around valve rod, and no leakage from the pneumatic chamber to both outside and the small hydraulic chamber. Neither was there any leakage of the hydraulic fluid in the small hydraulic chamber.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Gas Pressure (MPa) | 31.95 | 47.56 | 55.12 | 66.20 | 78.13 | 92.25 |
| Liquid Pressure (MPa) | 49.50 | 62.85 | 77.12 | 87.60 | 99.91 | 114.00 |
| △ P (MPa) | 17.55 | 15.29 | 22.00 | 21.40 | 21.78 | 21.75 |

| 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| 100.81 | 120.95 | 146.25 | 156.91 | 169.50 | 182.20 | 198.05 | 202.15 |
| 124.61 | 144.23 | 165.10 | 171.90 | 181.82 | 192.30 | 201.85 | 204.80 |
| 23.80 | 23.28 | 18.85 | 14.99 | 12.32 | 10.10 | 3.80 | 2.65 |

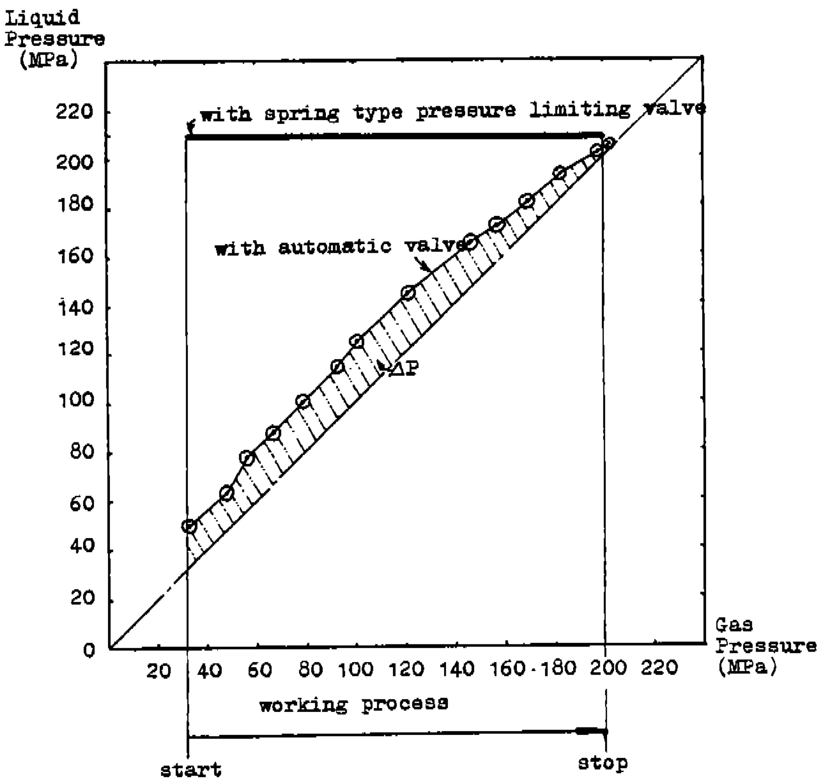



Fig.6 Liquid-gas Pressure Curve Of GME200 Diaphragm Compressor

c) The valve needle is nimble. The action frequency of the valve needle is 350 times per minute, equal to the revolution of the compressor. The conical of the valve can offer a good sealing.
d) The performance repeatability of the valve is proved satisfactory by large numbers of test recordings.

Conclusion:

This type of automatic pressure regulating valve is suitable for superhigh pressure diaphragm compressor with max. discharge pressure up to 200 MPa(29000 psi). It can function as auto-control of liquid-gas pressure differential.

In comparision with manual pressure control valve, it can realize unmanned operation of the diaphragm compressor. Compared with spring type valve, it can reduce greatly the liquid-gas pressure differential.

To compare by GME200 diaphragm compressor, the liquid-gas pressure differential at the begining of pressurizing process, the pressure differential with automatic pressure regulating valve is only 9.86% of the value with spring type pressure limiting valve(see Fig.6).

Thus, this type of automatic pressure regulating valve alleviated greatly the destructive power of the additional local stress and created favourable conditions for the increasing service life of diaphragm.

## CONCLUSION REMARKS

1. The running of GME200 diaphragm compressor has proved that the train of thought, i.e. taking compressor discharge pressure as the controlling pressure to limit the peak value of liquid pressure is correct. Furthermore, the pneumatic-hydraulic converting construction in this automatic pressure regulating valve is the crux of the matter which makes it possible to improve the performance of superhigh pressure diaphragm compressor.
2. On the basis of the principle of the valve, it can be used in any type of diaphragm compressor with higher or lower discharge pressure.

## ACKNOWLEGEMENT

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Shanghai Dalong Machinery Works has made great efforts in the trial-manufacture of the valve and compressor.