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# VARIABLE VOLUME-RATIO AND CAPACITY CONTROL IN TWIN-SCREW COMPRESSORS

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## ABSTRACT

This paper presents different means for variable built-in volume ratio and capacity control for the twin-screw refrigeration compressor. Sophisticated methods for such controls are mostly needed on refrigeration compressors but are of course applicable to any twin-screw compressor.

Two different types of variable built-in volume ratio are presented: $V_i$ slide valve and $V_i$ lift valve.

For capacity control, emphasis is placed on suction-port control and variable speed. The different means presented for suction port control are:

- capacity slide valve regulating discharge port
- capacity slide valve which does not regulate the discharge port
- capacity slot valve
- capacity lift valve

Each capacity control arrangement is studied in conjunction with fixed and variable built-in volume ratio.

## INTRODUCTION

The twin screw compressor has, due to its "fixed" ports, a built-in volume ratio ($V_i$). The draw-back of this is that the compressor can not operate efficiently over a wide pressure ratio range, because of over- or under- compression. However, a compressor with variable built-in volume ratio can cover a wide range of operating conditions with high performance at full- and part-load. The benefit of variable built-in volume ratio is even more accentuated when the compressor operates with economizer or side load.

Other indirect features of the variable built-in volume ratio:

- no oil foam in oil (no over-compression) and therefore less oil carried over into the refrigeration system
- no overloaded motors or shafts (assuming constant discharge pressure)
- extended bearing lift (minimized load on bearings)
- more efficient liquid refrigerant injection possibilities
- extended efficient operating range with economizer (discharge port corrected for flash gas from economizer as well as gas coming from suction)

Capacity control has been applied to compressors in order to meet the load requirements. For twin-screw compressor there are many ways of controlling capacity because it is a positive displacement machine with continuous compression.

The base principles of capacity control are throttling, by-pass, suction-port control and variable speed.

## BUILT-IN VOLUME RATIO ($V_i$) CONTROL

For varying the built-in volume ratio, slide valves or lift valves can be used.

### $V_i$ Slide-Valve

Definition:

A valve, having a sliding action parallell to the rotor bores,situated within the high pressure cusp region, facing one or both rotor bores and controlling the radial discharge port.

The axial port is designed for a value corresponding to the highest $V_i$ required.

Example:

Fig. 1 shows a developed view of the twin-screw compressor, equipped with a $V_i$ slide valve. It can vary the $V_i$ continuously or in steps. Fig. 2 shows the compressor performance with a $V_i$ variation from 2 to 5.7. The performance with fixed $V_i$ 2.7 is shown for comparison.

### $V_i$ Lift Valve

Definition:

A valve within the discharge region, facing one or both rotor bores (including outlet endplane) and opening an "extra" radial or axial port when a lower $V_i$ is required.

The "fixed" discharge port is determined with regard to the highest pressure ratio in operation. One $V_i$ lift valve means two-step $V_i$ control, two $V_i$ valves means three step $V_i$ control, etc. (Fig. 4).

Example:

Fig. 3 shows a $V_i$ lift valve (radial lift valve on the female side) in a developed view of the twin screw compressor. Fig 4 shows performance with such a $V_i$ lift valve giving two step $V_i$ control: 2.8 and 4.0 for this example. The performance with $V_i$ slide valve (2.0-5.7) is shown for comparison.

## CAPACITY CONTROL

### Throttling

Definition:

Throttling means that the capacity is reduced by a throttling valve in the suction side of the compressor.

This method works better the higher the built-in volume ratio is. For a $V_i$ of about 2.3 there is no power reduction at all but for a $V_i$ larger than 2.3 there is some power reduction and for a $V_i$ lower than 2.3 there is actually some power increase when throttling. This means that a compressor with variable built-in volume ratio comes out better than a fixed built-in volume ratio compressor when throttling.

Example:

Figure 5 shows part load performance with throttling, for a fixed $V_i = 2.7$ and for variable $V_i = 2.7 - 5.7$.

## By-Pass

By-pass means that the capacity is reduced by by-passing discharge gas to the suction side of the compressor. Since this method does not decrease the power consumption with decreased capacity and is independent of built-in volume ratio it will not be further discussed.

## Capacity Slide Valve

Definition:

A valve with sliding action parallell to the rotor-bores, situated within or close to the high pressure cusp region, facing one or both rotor bores, controlling the radial suction port and/or by-passing intermediate pressure gas to suction.

Within this definition there are two types of capacity slide valves.

1) Capacity slide valve regulating discharge port;

A slide valve within the high pressure cusp region, with "low-pressure end" controlling capacity and "high pressure end" forming the radial discharge port (standard capacity slide valve).

The axial port is designed for a value giving good part-load performance without losing full-load performance. Varying the length of the slide valve gives different built-in volume ratios at full load. The "slide stop" is normally situated at 90° male turning angle from start of compression. This type has been most widely used, due to its ability to "correct" the built-in volume ratio at part load.

Example:

Fig. 6 shows a capacity slide valve. Fig. 7 shows part load performance at different pressure ratios, where each pressure ratio has an optimum built-in volume ratio at full load.

If the slide stop is movable, the compressor will have variable $V_i$. Fig. 8 shows a capacity slide valve regulating discharge port and with movable slide stop. Its part-load performance is practically the same as a slide valve with fixed slide stop, but if we assume pressure ratio change during part load, the movable slide stop is superior.

2) Capacity slide valve which does not regulate the discharge port; a slide valve outside the high-pressure cusp region controlling capacity only.

The part-load performance in this case is lower than with the standard capacity slide valve due to the absence of $V_i$ correction at part load. The part-load performance is similar to the capacity slot valve.

Example

Fig. 9 shows a capacity slide valve which does not regulate discharge port.

Fig. 10 shows a capacity slide valve in combination with a separate $V_i$ slide valve. This configuration gives very independent capacity control and $V_i$ control.

The arrangement is also very attractive for economizer duty as the economizer effect can be obtained even below 50 per cent capacity.

Capacity Slot Valve

Definition:

A plunger or turn valve, gradually opening a number of slots following the rotor helix and facing one or both rotor bores

These recesses in the casing wall, however, increase the volume of the compression space and create leakage paths over the lobe tips. The result is somewhat lower full-load performance as compared to a design without slots.

The part-load performance is lower than with a standard capacity slide valve due to the absence of $V_i$ correction at part load. Separate means for $V_i$ control will of couse change this situation. One positive aspect of the capacity slot valve design is the possibility for valve-rotor interference is eliminated.

Example:

Fig. 11 shows a capacity slot valve arrangement. Fig. 12 shows part load performance for a capacity slot valve.

Capacity Lift Valve

Definition:

A valve within the internal compression region, facing one or both rotor bores (including outlet endplane) and delaying the actual start of compression when opened.

Axial capacity lift valves are flat towards the rotors and radial capacity lift valves are normally concave towards the rotors.

Example:

With separate $V_i$ control the capacity lift valve gives similar part load performance as the standard slide valve but with step function.

Fig. 13 shows two capacity lift valves (radial lift valve on male and female side) in a developed view of the twin screw compressor. Fig. 14 shows part load performance for two capacity lift valves and with variable $V_i$.

## Variable Speed

The capacity is controlled by variation of the rotor speed. This means that the cost for capacity control is moved from the compressor to the driving system.

When comparing variable speed (i.e. frequency-controlled motor) with suction port capacity control, it is very important to include also the motor and motor control efficiencies, since the efficiencies not only depend on load but also on speed. In order to obtain a wide capacity range for a small speed range, the compressor should have a dynamic suction port. A dynamic suction port is a port in which closing takes place later than at maximum thread volume and where the inlet area is very small between the points of maximum thread volume and closing (see fig. 15). In this way the effective displacement is varied with the rotor speed. Another benefit is lower torque at lower speed, compared with standard suction port.

Fig. 16 shows the performance of a very simple dynamic suction port, i.e. open inlet bores. The volumetric efficiency is shown with two definitions. The two definitions are:

a) Theoretical volume is equal to maximum thread volume

b) Theoretical volume is equal to volume at closing of thread.

The performance is also compared to that with a standard inlet port where the maximum thread volume is equal to volume at closing of thread. In figure 16 we can see that a dynamic suction port compressor has somewhat lower adiabatic efficiency at low speed than a standard suction port compressor. If, however, the comparison is made at the same capacity, they have about the same adiabatic efficiency.

This means that the dynamic suction port variable speed compressor can handle a certain capacity range with a smaller speed range and therefore will obtain higher motor and inverter efficiencies than a standard suction port variable speed compressor.

In relation to this, it is worth pointing out that compressors like the Single-Screw and the Scroll are designed to close suction after maximum "thread" volume and they therefore show "high" volumetric efficiencies, based on a theoretical volume equal to volume at closing of "thread".

## CONCLUSIONS

This paper has shown many possible designs for regulation/control of the twin-screw compressor. It has dealt with different ways of meeting the demand for built-in volume ratio control and capacity control. It is therefore easy to understand that the twin-screw compressor is very "flexible" and can be adapted for very specific needs. The different means for variable volume ratio and capacity control are quite easy and cost effective to include in the twin-screw compressor design since it only has one working chamber.

The main points to consider when selecting variable volume-ratio and capacity control system are:

- application
- first cost
- operating cost
- reliability

Among all applications possible, there will probably be sets of conditions where each type of volume ratio variation and capacity control can be justified. However, the following general trends in refrigeration twin-screw compressor design can be recognized.

| Smaller Compressors | Larger Compressors |
|---|---|
| (below appr.300 $m^3$/h(180 CFM)) | (above appr.300$m^3$/h(180 CFM)) |
| - capacity lift valve(s) and/or two-pole motor or continuosly-variable-speed motor | - capacity slide valve which does not regulate the discharge port |
| | - $V_i$ slide valve |
| - $V_i$ lift valve (possibly $V_i$ slide valve together with variable speed) | - economizer effective also at part load |

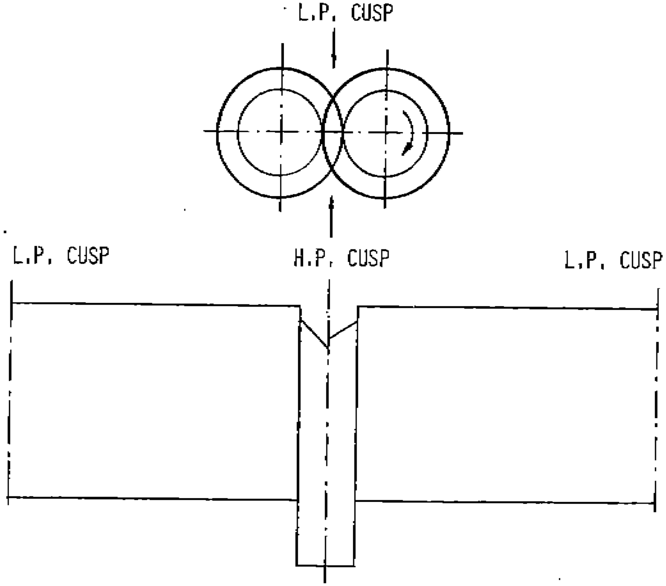
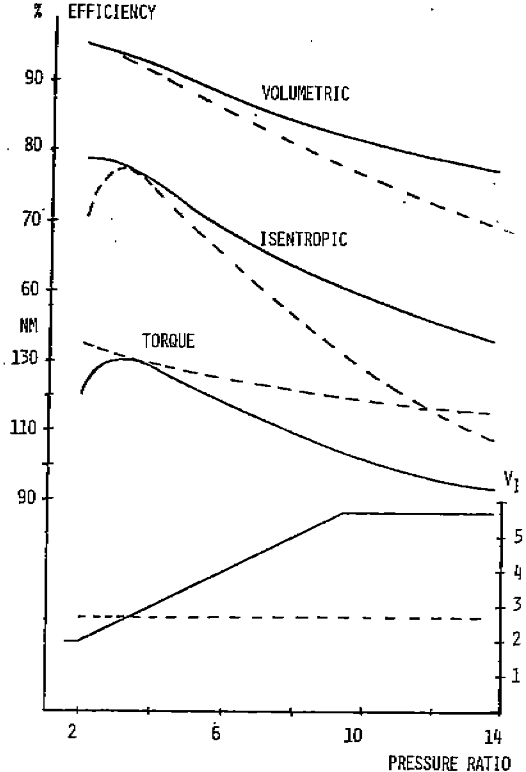


FIG 1: $V_I$ SLIDE VALVE



R 22 COND. TEMP: 54.4°C (130°F)
LIQ. REF. INJ. TYPE

FIG 2: PERFORMANCE WITH $V_I$ SLIDE VALVE

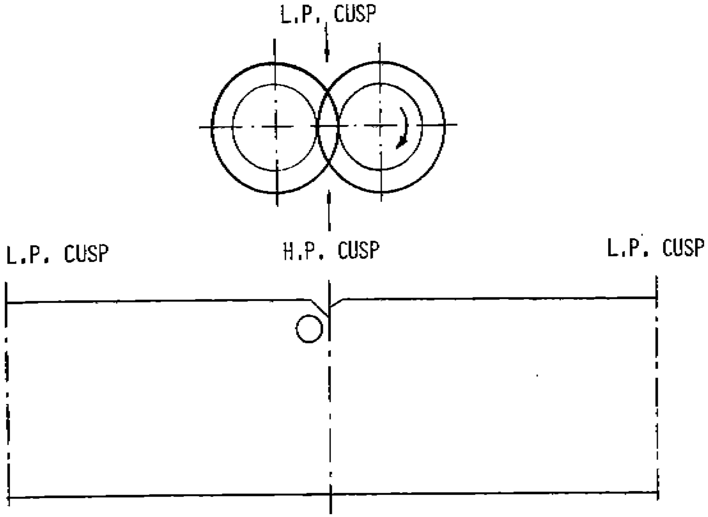
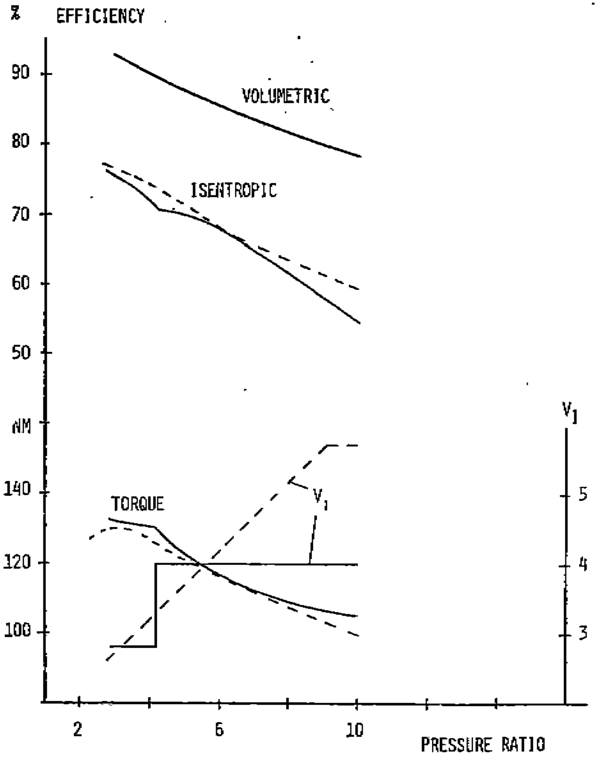
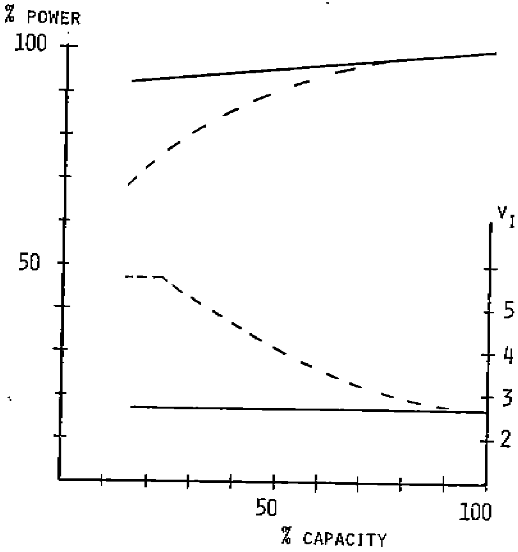


FIG 3: $V_1$ LIFT VALVE



R22 COND. TEMP: 54.4°C (130°F)
LIQ. REF. INJ. TYPE

FIG 4: PERFORMANCE WITH $V_1$ LIFT VALVE



R22 COND. TEMP: 54.4°C (130°F)
PRESSURE RATIO:3

FIG 5: PART LOAD PERFORMANCE WITH THROTTLING

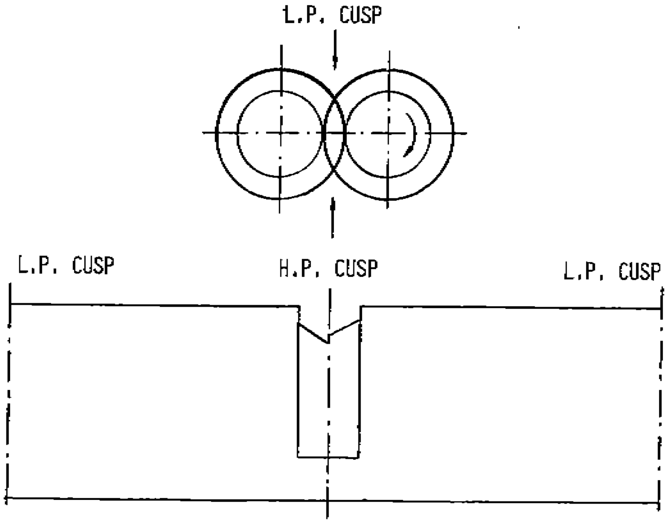
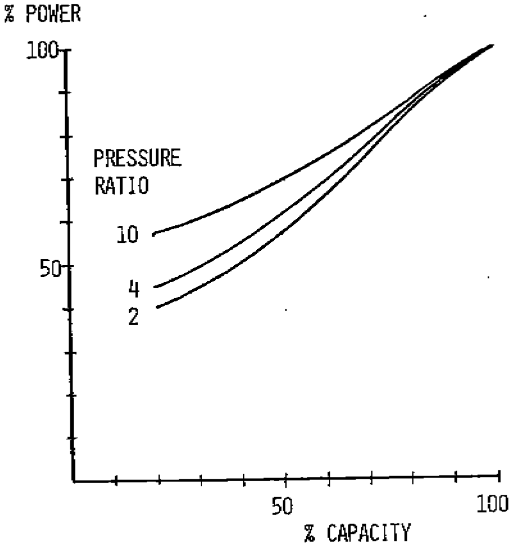


FIG 6: CAPACITY SLIDE VALVE REGULATING DISCHARGE PORT



R22 COND. TEMP.: 40°C

FIG 7: PART LOAD PERFORMANCE FOR A SLIDE VALVE (REGULATING DISCHARGE PORT)

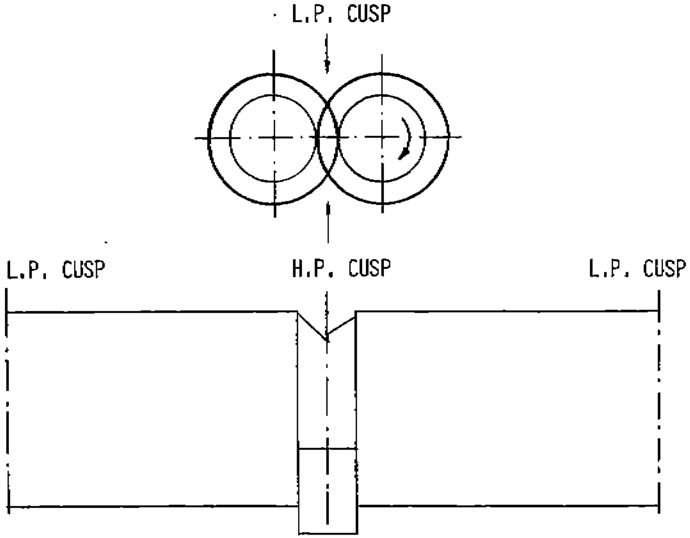


FIG 8: CAPACITY SLIDE VALVE REGULATING DISCHARGE PORT AND WITH MOVABLE SLIDE STOP

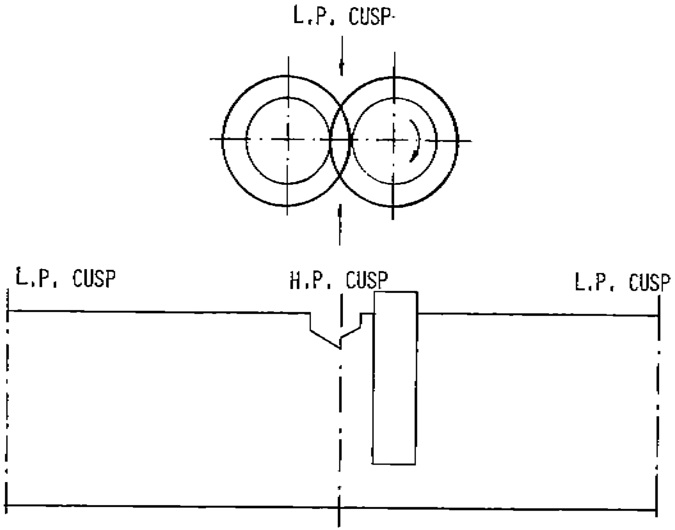


FIG 9: CAPACITY SLIDE VALVE WHICH DOES NOT REGULATE DISCHARGE PORT

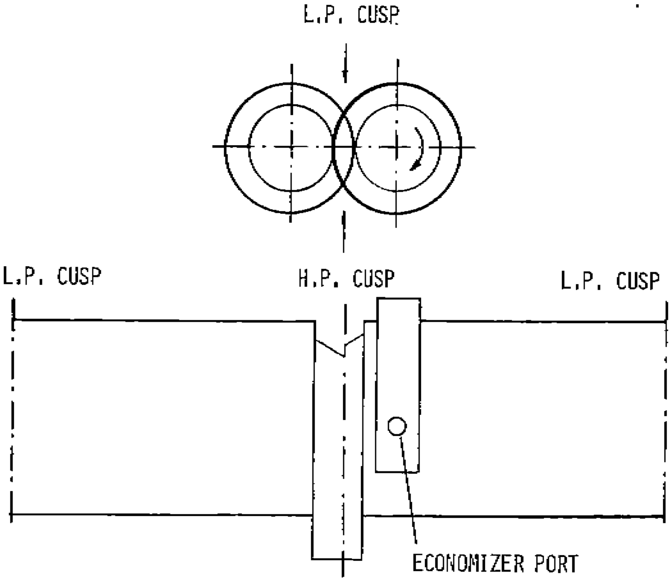


FIG 10: CAPACITY SLIDE VALVE WHICH DOES NOT REGULATE DISCHARGE PORT AND WITH SEPARATE $V_i$ SLIDE VALVE

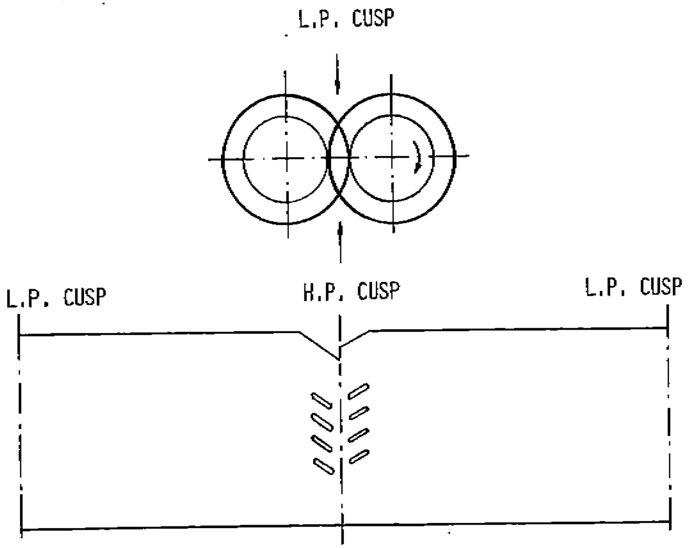
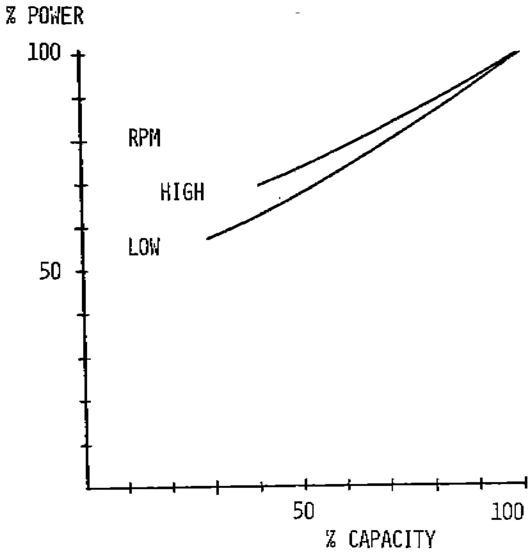


FIG 11: CAPACITY SLOT VALVE



R22 COND. TEMP: 40°C
PRESSURE RATIO: 4

FIG 12: PART LOAD PERFORMANCE FOR A CAPACITY SLOT VALVE

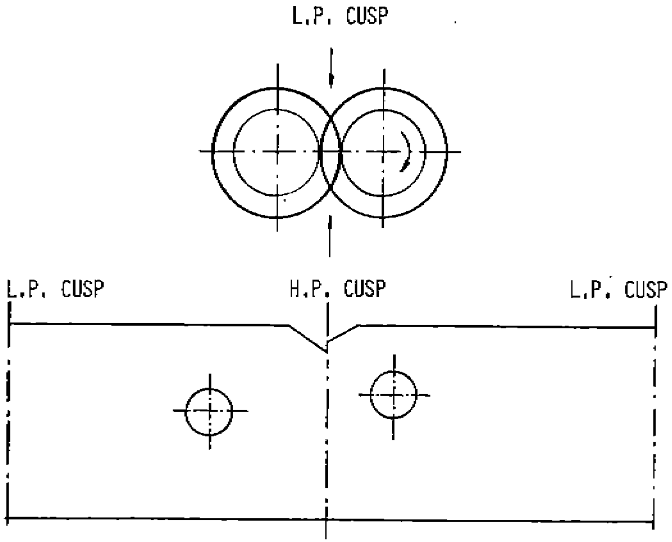
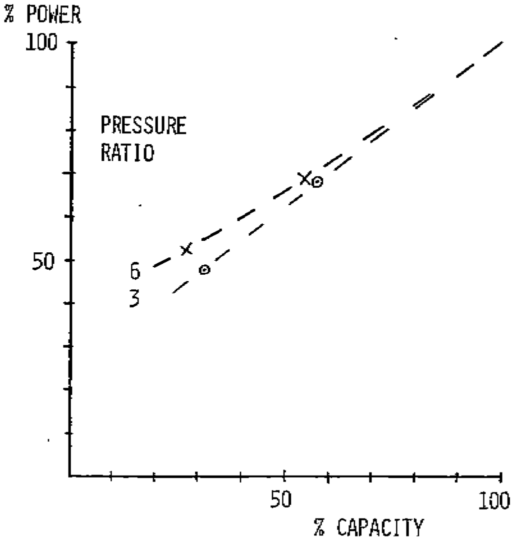


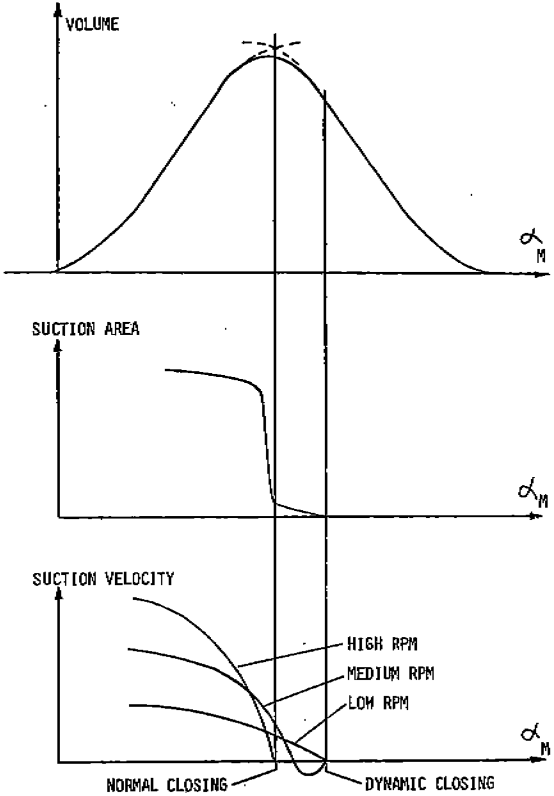
FIG 13: CAPACITY LIFT VALVES



R22 COND. TEMP: 40°C

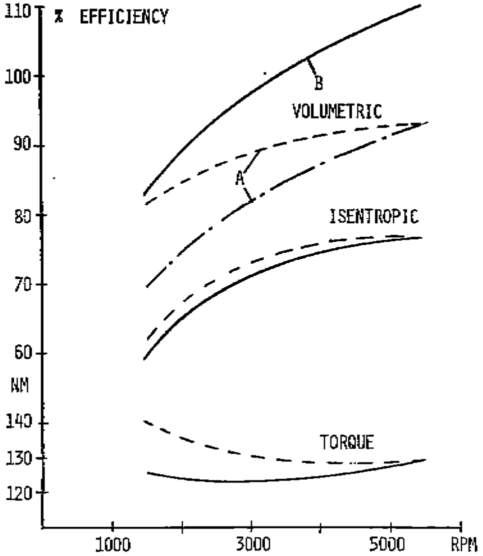
$V_I$: OPT. ($V_{IMAX}$: 5.7)

FIG 14: PART LOAD PERFORMANCE FOR TWO CAPACITY LIFT VALVES AND VARIABLE $V_I$



$\alpha_M$-MALE TURNING ANGLE

FIG 15: PRINCIPLE OF DYNAMIC SUCTION PORT



A: THEORETICAL VOLUME = MAXIMUM THREAD VOLUME

B: THEORETICAL VOLUME = VOLUME AT CLOSING OF THREAD

——— —·— DYNAMIC SUCTION PORT

- - - - NORMAL SUCTION PORT

R22 COND. TEMP: 54.4°C (130°F)

PRESSURE RATIO: 3.45

LIQ. REF. INJ. TYPE

FIG 16: PERFORMANCE FOR DYNAMIC SUCTION PORT