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RESEARCH OF OIL–INJECTED SCROLL COMPRESSOR WORKING PROCESS

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ABSTRACT

The working process of oil–injected scroll compressor is analysed in this paper. The thermodynamic and dynamic models are developed for the oil–injected scroll compressor. The property parameters can be calculated under the influences of the leakage and the friction. The results of computer simulation are coincident with the experiment's. so it is useful to predict the compressor performance.

INTRODUCTION

Scroll compressors have shown their competitive advantages in the markets of heat pump air–conditioners and refrigerators for their high efficiency, low noise and vibration, small size and light weight. Since the first set of scroll compressor has been developed in China, we devoted to the studies and researches of them, and put them into wide applications.The concept of scroll compressor was first described in the U.S patent in the early 1900s, but was not fully developed in practical application until recently, one of the important reasons for this is due to the leakage losses through the clearances between scroll wraps, as shown in Fig.1, this can reduce the volumetric efficiency and increase the energy losses. When the pressure differences between two near working pockets are constant, the directly determining facter of the leakage losses is the size of the clearances, the appearance of the precise production techniques can control the range of the radial clearances within reasonable area, but the axial clearances are connected with the maching, installing and forces acting on the wraps, furthermore, the radial leakage losses are much higher than tangential's, so it's necessary to take some measures to reduce the leakage losses. The structure shown in Fig.2 is a very typical mechanical sealing mechanism for this purpose.

A sealing element is inserted tightly in the groove machined on the top of the wrap to prevent radial leakage, although it can increase the volumetric efficiency, it has its disadvantages, the groove is milled after the scroll wrap has been machined, it is long and very narrow, and needs long time and high precision to be milled, and at the same time, this process can easily broken the milling cutter, this will mainly influence the cost of the machine. Besides, the installment of the sealing element is fairly complex, and the widen of the wrap will increase the size and the weight of the scroll, on the other hand, the structure will create extra axial sealing forces, relevantly enlarge the friction losses and fluid flow losses, in these cases, oil–injected scroll compressor emerges as the times require.

One of the characters of the oil–injected scroll compressor is each of its wrap has no sealing element, this simplizes its structure, reduces its cost, can be easily machined and installed. Oil with specific pressure is injected into the working pockets, shown in Fig.3, it produces oil membranes on the surfaces of the pockets, this lessens the practical clearances of gas leakage paths, meanwhile, the oil has cooling and lubricating effects, so the research of it is significant and it has brilliant prospects.

THE FOUNDATION OF THE COMPUTER MODEL

The working process of oil–injected scroll compressor can be divided into the suction process, the compression and the discharge process, in order to simplify the calculations, following assumptions are made.

1. Gas is treated as an ideal gas with a constant specific heat, the properties of the working fluid is homogeneous throughout the working space at any instant.
2. Gravitational and kinematic energies of the working fluid are neglected.
3. Phase change does not occur, the oil and the gas is not mutual dissolution.
4. The working pockets are adiabatic, during the suction–close, compression and discharge process, the oil and the gas has no heat exchange.
5. The external actions on the working pockets at any instant are homogeneous, other assumptions will be illustrated afterwards.

• Analytical Model

From the points of Mass Exchange Thermodynamics, the mass flow of the leakage, the suction and the discharge processes are all the mass exchanges of the working pockets with the outside world, so we define the paths of the above as paths of mass exchange, the whole working process can be unified as the same equation form, two symmetry working pockets are selected as control space, the schematic diagram of the analytical model is shown in Fig.4.

From the First Law of Thermodynamics, the Law of Conservation of Mass, and the Ideal Gas State Equation, the following differential equations are obtained.

$$\frac{dm_g(\theta)}{d\theta}=\frac{\dot{m}_{g_e}(\theta+2\pi)}{\omega}-\frac{\dot{m}_{g_e}(\theta)}{\omega}$$

$$\frac{dm_l(\theta)}{d\theta}=\frac{\dot{m}_{l_e}(\theta+2\pi)}{\omega}-\frac{m_{lo}(\theta)}{\omega}$$

$$\frac{dV_g(\theta)}{d\theta}=\frac{dV_{goo}(\theta)}{d\theta}-\frac{1}{\rho_l(\theta)}\frac{dm_l(\theta)}{d\theta}$$

$$\frac{dT_g(\theta)}{\theta}=T_g(\theta)\left[\left(\frac{RT_g(\theta+2\pi)}{T_g(\theta)}-1\right)\frac{\dot{m}_{ge}(\theta+2\pi)}{m_g(\theta)\cdot\omega}-(K-1)\frac{\dot{m}_{go}(\theta)}{m_g(\theta)\cdot\omega}\right]$$
$$-\frac{T_g(\theta)(K-1)}{V_g(\theta)}\frac{dV_g(\theta)}{d\theta}$$

$$\frac{dT_l(\theta)}{d\theta}=T_l(\theta)\left[\frac{T_l(\theta+2\pi)}{T_l(\theta)}-1\right]\frac{\dot{m}_{le}(\theta+2\pi)}{m_l(\theta)\cdot\omega}$$

$$\frac{dP(\theta)}{d\theta}=-KP(\theta)\left[\frac{dV_g(\theta)}{V_g(\theta)d\theta}-\frac{T_g(\theta+2\pi)\cdot\dot{m}_{ge}(\theta+2\pi)}{m_g(\theta)\cdot\omega\cdot Tg(\theta)}+\frac{T_g(\theta)\cdot\dot{m}_{go}(\theta)}{m_g(\theta)\cdot\omega\cdot T_g(\theta)}\right]$$

By using of these equations, change of the state of the working fluid can be calculated in a step–by–step procedure.

· The Suction Process Model

The relationship between the volume of the control space and the orbiting angle is shown in Fig.5.

The suction process ranges from $\theta=[0,\ 360°]$, at a specific angle, the volume reaches its maximum, we define the stage of the $V=[V_{max},\ V_{360°}]$ as the suction–close process, during the stage, the volume reduction rate is very fast, the inner suction apertures have not closed, their areas are very small, and are reducing to zero, so the pressure of the control space is higher than the suction pressure P_s , at the same time, working fluid return flow occurs, we assump that only gas returns, the return flow rate is one–dimensional flow of a compressible fluid, this stage is shown in Fig.6.

$$\dot{m}_o(\theta)=\alpha_s(\theta)\cdot s(\theta)\cdot\sqrt{\frac{2K}{K-1}\frac{P_1}{v_1}\left(v^{\frac{2}{K}}-v^{\frac{K+1}{k}}\right)}$$

$$P_2/p_1\quad\geqslant v_c=\left(\frac{2}{K+1}\right)^{\frac{K}{K-1}},\qquad v=P_2/P_1$$
$$P_2/P_1\quad<v_c,\qquad v=v_c$$

· Model of Discharge Process

Scroll compressor is a positive discharge mechanism, during this period, if the pressure of the control space $p(\theta)$ is higher than discharge pressure p_d , i.e. $P(\theta) > P_d$, the discharge flow rates through the inner discharge apertures increase, until their pressure approachs P_d gradually, the flow rate is obtained using the equation of oil and gas two–phase flow through orifice,

$$\dot{m}_m = \frac{\varphi C_D f \sqrt{2 \cdot \Delta P_{TP} \cdot \rho_l}}{\sqrt{1-\beta^4}\left[(1-x)\theta_o + x\sqrt{\frac{\rho_l}{\rho_g}}\right]}$$

$$\dot{m}_l = (1-x)\dot{m}_m$$

$$\dot{m}_g = x\dot{m}_m$$

If $P(\theta) < P_d$, return flow occurs, also assumping only gas returns, the mass flow rate is obtained using the same equation of flow at suction –close stage.

• Model of Leakage flow

The radial leakage flow rate is obtained using the flow model through the clearance between involute semi–circle ring and plate, it is radiative–shaped flow radially as shown in Fig.7.

$$Q_{mr} = \frac{L_l(\theta)\left[\delta^3_{a_1} + \delta^3_{a_2}\right]}{24\bar{v}t}\,[P_1(\theta) - P_2(\theta)]$$

The tangential leakage flow rate is obtained using the flow model through the clearanc between two parabolic cylinders with main shaft coinciding with each other.

$$Q_{mt} = \frac{h\delta^3_{rs}(P_1 - P_2)}{10.02\mu\sqrt{\delta_{rs} \cdot \frac{R_1 R_2}{R_2 - R_1}}}$$

R_1, R_2 are the curvature radii of the simplized parabolic cylinders shown in Fig.8.

COMPUTER FRAMES

Computer flow charts including the main program and the radial and tangential leakage progroms are shown in Fig.9~Fig.11.

The main program requires physical characteristics of the machine and the operating parameters as input. The mass flow rate and the properties of the working fluid are calculated at a small integration step using the Rung–Kutta method. AFter completion of each cycle, the adiabatic efficiency is calculated and compared with calculation for the previous cycle, this calculation is iterated until the system converges, finally, the properties of the working fluid at every orbiting angle are obtained.

RESULTS AND DISCUSSION

A variety of performance experiments are carried out at constant orbiting speed and various operation pressure, while changing oil flow rate and oil–injection temperature, the experimental results of a selected operating condition are in good agreements with that of calculation's, as shown in Fig.12~ Fig.14. the comparisions show that errors between the experiments and calculations are no more than 4~ 5%, besides, the pressure, the mass of the gas and the mass of oil in control space are also calculated, as shown in Fig.15~Fig.17.

CONCLUSIONS

A computer model of oil–injected scroll compressor is developed. The model includes the analysis of the working fluid properties in control spaces, the influences of the leakage losses and mechanical losses are considered, then it calculated the performance parameters.

The results of calculation and experiment on sample scroll compressor proved the following:

1) On the same machine, installment and operating conditions, compared with none oil–injected scroll compressor, oil–injected scroll compressor can reduce the specific capacity by 9.41%, increase the volumetric efficiency by 4.3%, reduce the discharge temperature by 30%, therefore the compression ratio of the single step compressor can be raised.
2) Generally, the injected oil temperature is higher than the suction gas temperature, this results the reduction of the volumetric efficiency and the rise of the gas temperature at the end of the suction process; the suction–close process will lead to the rises of the gas pressure and the volumetic efficiency, the final result is that volumetric efficiency is raised.
3) The present computer model can be used to predict the performances of oil–injected scroll compressors and also proved the feasibility and the importance of putting this new kind of machine into practice.

NOMENCLATURE

C_p = specific heat at constant pressure
C_v = specific heat at constant volume

C_d = coefficient of mass flow rate
F_f = specific capacity
h = wrap height
k = adiabatic coefficient
P = pressure of working fluid
V = volume of working fluid
T = temperature of working fluid,
E = energy
P_s = suction pressure of gas
T_s = suction temperature of gas
P_d = discharge pressure of gas,
T_d = Discharge temperature of gas
m = mass of working fluid
Q_{oj} = injected oil flow rate
θ = orbiting angle
T_{oj} = injected oil flow temperature
ω = orbiting speed
N_s = capacity
R = gas constant
η_v = volumetric efficiency
L = length of leakage line
η_{ad} = adiabatic efficiency
φ = correct flow rate coefficient
μ = dynamic viscosity
= motive viscosity
$x = \dot{m}_g / \dot{m}_m$.
subscript: "m" = gas and oil
"l" = oil
"g" = gas
"o" = leakage

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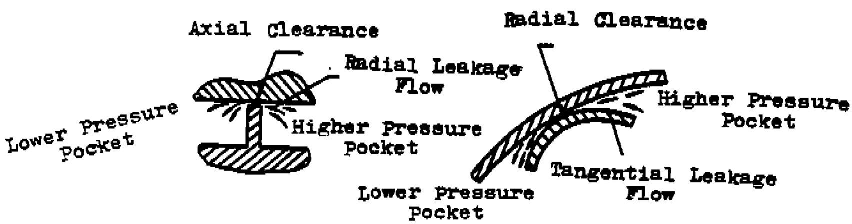
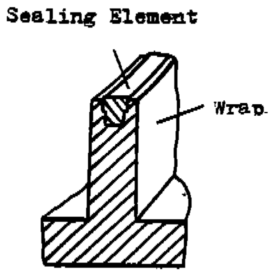


Fig.1 Leakage Flows



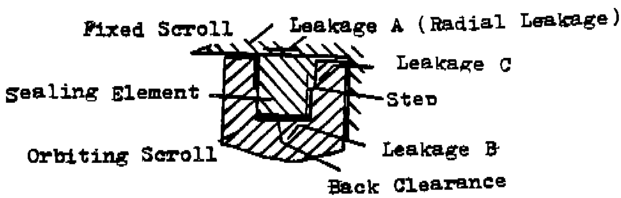


Fig.2 Axial Sealing Mechanism

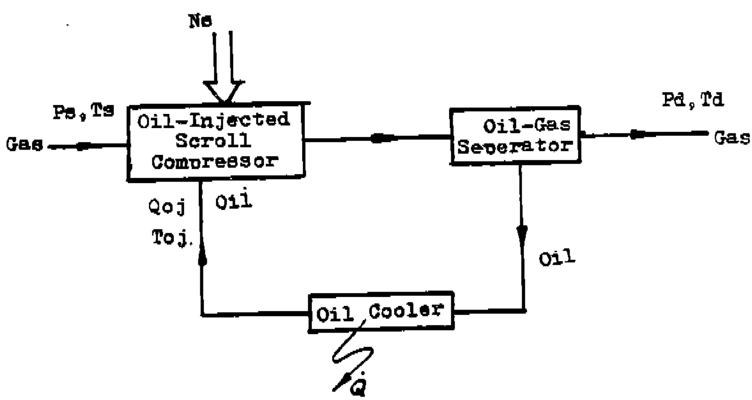


Fig.3 Oil-Injected Scroll Compressor System

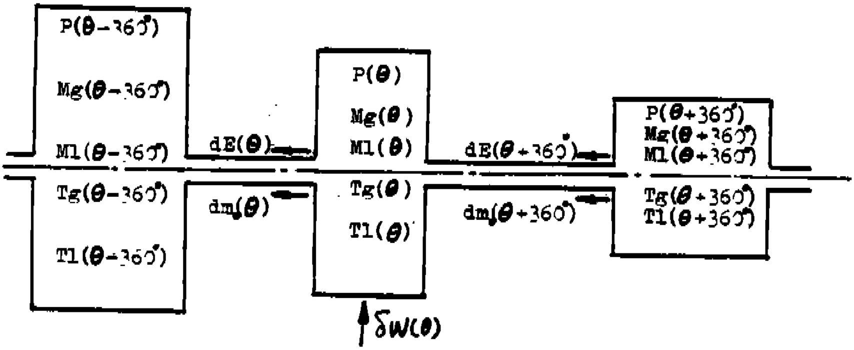


Fig.4 Analytical Model of Oil-Injected Scroll Compressor

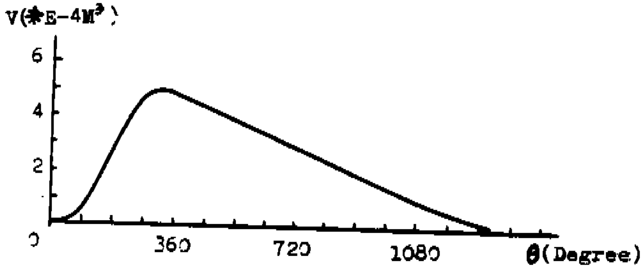


Fig.5 Volume In Control Space

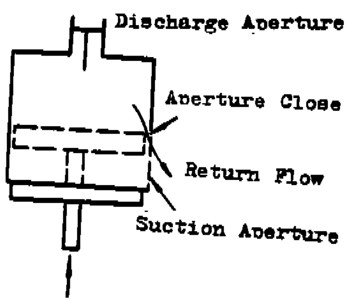


Fig.6 Suction-Close Process

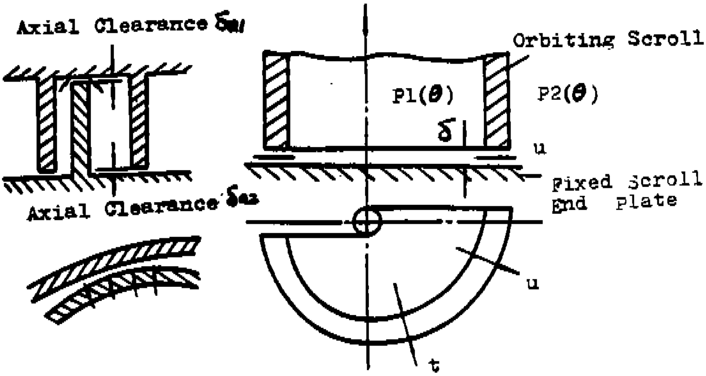


Fig.7 Radial Leakage Model

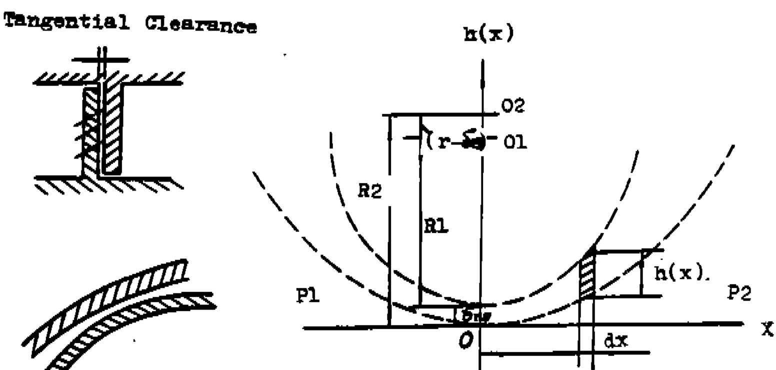


Fig.8 Tangential Leakage Model

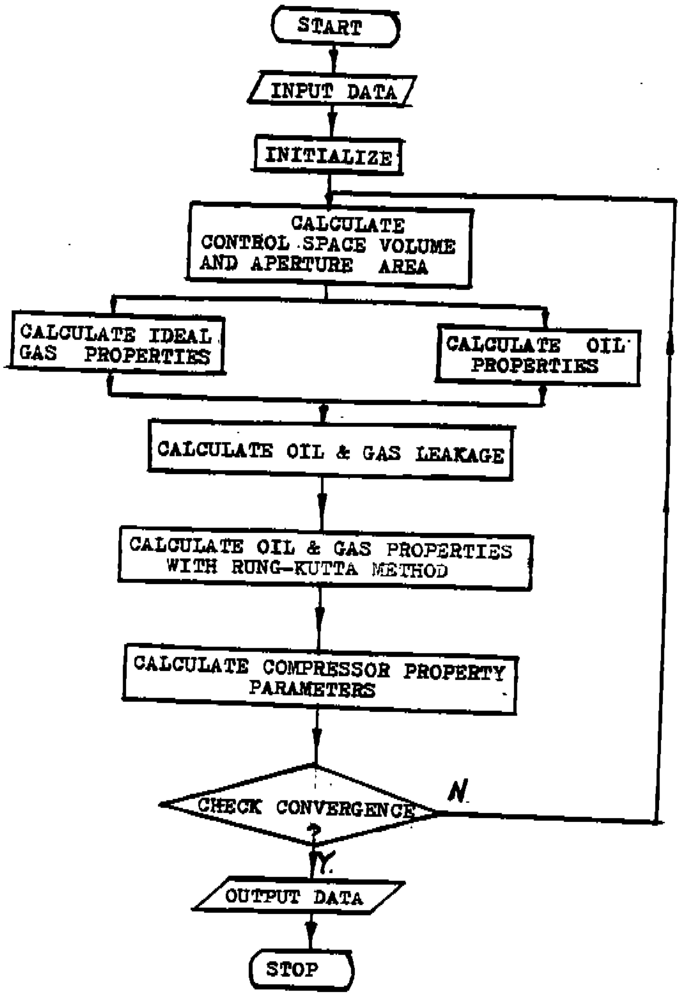


Fig.9 The Main Program Flow Chart

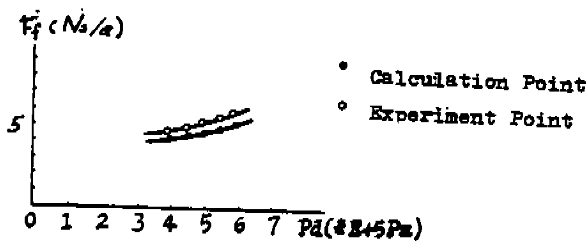
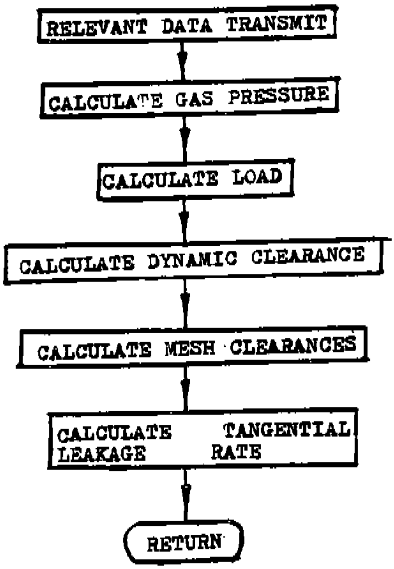


Fig.14 Specific Capacity



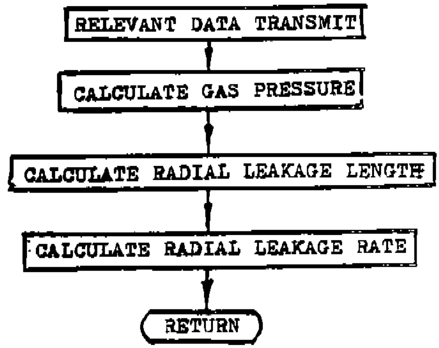


Fig.11 The Radial Leakage Program

Fig.10 The Tangential Leakage Program

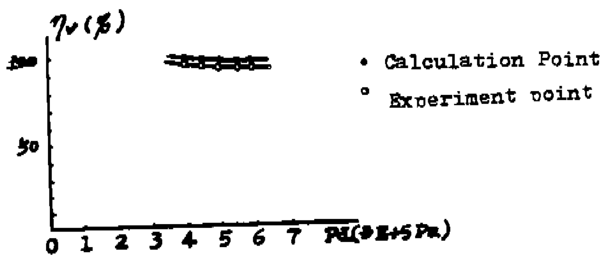


Fig.12 Volumetric Efficiency

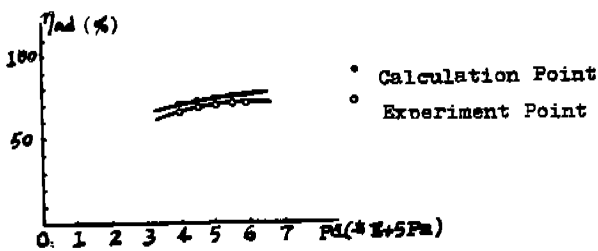


Fig.13 Adiabatic Efficiency

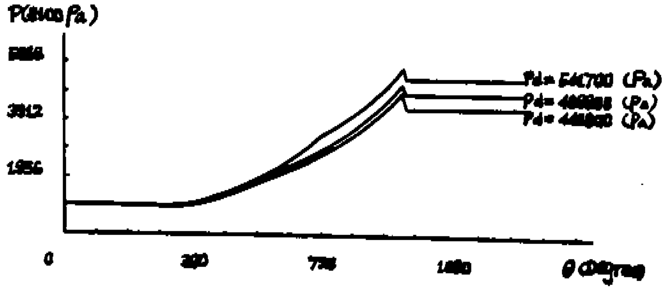


Fig.15 Pressure In Control Space

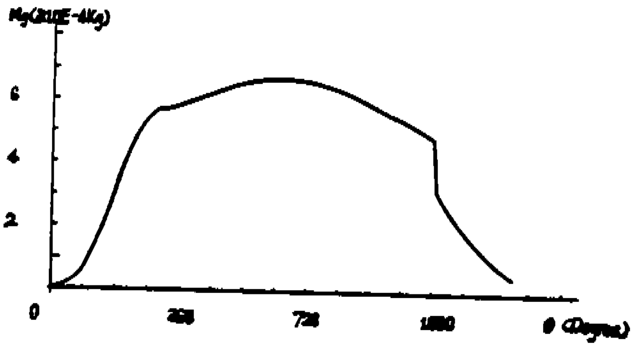


Fig.16 Gas Mass In Control Space

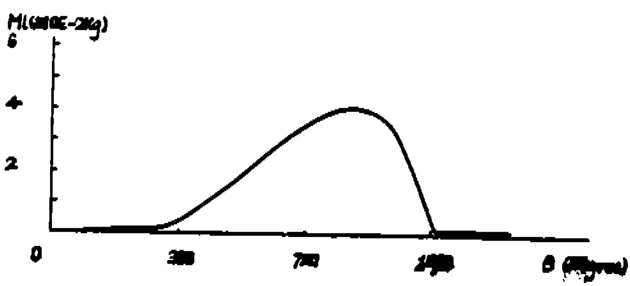


Fig.17 Oil Mass In Control Space