往复式压缩机网状阀倾侧运动研究

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把往复式压缩机网状阀片的运动看作平动和转动的复合运动，并以偏离气缸截面安装的带缓冲片网状阀为例，建立由于气流偏吹引起的阀片倾侧运动的数学模型，并通过实验得到验证，最后与阀片单质点数学模型的结果进行了比较。

关键词 往复式压缩机 网状阀 倾侧运动

符 号 说 明

A_{efz}、A_{efc}——正吹、偏吹区间有效通流面积；
A_g——阀隙通流面积；
A_p——阀片迎风面积；
F_c、F_z——偏吹、正吹区间气体力；
h_v、h_H——阀片、缓冲片弹簧预压缩量；
H_1——气阀未开启状态阀片到缓冲片距离；
H_2——气阀升程；
I_v、I_H——阀片、缓冲片对 y 轴当量惯性矩；
k_v、k_H——阀片、缓冲片弹簧刚性系数；
K——绝热指数；
m_c、m_z——流过偏吹、正吹区间气体质量；
m_v、m_H——阀片、缓冲片当量质量；
M_c、M_z——偏吹、正吹区间气体力矩；
N——气缸同侧同名气阀个数；
P——气缸内气体压力；
P_s——吸气腔内气体压力；
R——气体常数；
T_s——吸气腔内气体温度；
V_h——气缸行程容积；
x_v、x_H——阀片、缓冲片弹簧中心 x 方向坐标；
Z——阀片各点的位移；
Z_c——阀片质心位移；
α——与 A_g 对应的气阀流量系数；
β——与 A_f 对应的推力系数；
γ——曲柄转角；
ε——相对余隙；
ϑ——阀片转角；
λ——曲柄半径连杆长度比；
v_s——吸气腔内气体比容；
ω——曲柄角速度。

网状阀在往复式压缩机中应用很广泛，网状阀工程设计时，为使压缩机具有良好的经济性和可靠性，要求气阀具有良好的运动规律。以往分析网状阀的运动规律时，通常把网状阀片当做仅有一维平动的单质点。事实上，由于流过气阀的气流不均匀、阀片与缓冲片弹簧力及分布质量不对称、阀座平面与升程限制器平面由于加工和装配误差存在夹角等原因，气阀工作过程中，阀片不仅作平动，而且存在转动，也就是说，阀片作倾侧运动。

为了减小阀片与升程限制器的碰撞速度，网状阀通常带有缓冲片，本文就以偏离气缸截面安装的带缓冲片网状阀为例，分析由于气流偏吹引起的气阀倾侧运动规律，并与不考虑倾侧运动的单质点数学模型结果进行比较。

1 倾侧运动数学模型的建立

以图1所示布置在盖侧的吸气阀为例，分析阀片的倾侧运动，阀片在气阀中按图2所示

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位置安放。

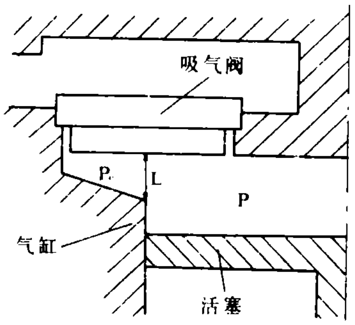

图1　吸气阀偏离气缸截面安装示意图

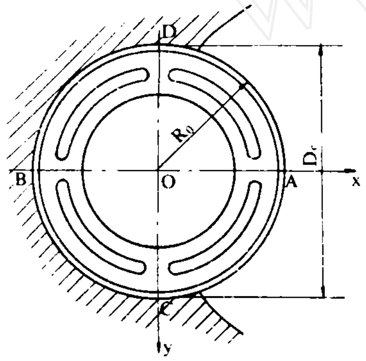

图2　阀片位置示意图

考虑阀片与缓冲片分布质量、弹簧力对称的情况，同时忽略气阀加工与装配误差，气流流过图2所示网状阀时，阀片的运动规律可看作与x轴对称，因此气阀工作过程中，阀片不存在相对于x轴的转动，仅考虑由于气流偏吹引起的相对于y轴的转动。如图3所示，o为质心。

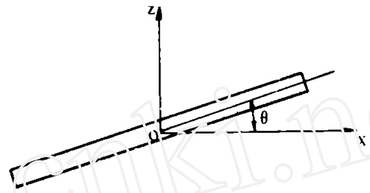

图3　网状阀片的倾侧运动

阀片未与缓冲片碰撞之前，可得如下运动方程：

$$m_v\frac{d^2Z_c}{dt^2}+(\Sigma k_{vi})Z_c=F_c+F_z-(\Sigma k_{vi})h_v \quad (1)$$

$$I_v\frac{d^2\theta}{dt^2}+(\Sigma k_{vi}x_{vi}^2)\theta=M_c+M_z \quad (2)$$

当阀片与缓冲片碰撞后，阀片与缓冲片一起运动，则为

$$(m_v+m_H)\frac{d^2Z_c}{dt^2}+(\Sigma k_{vi}+\Sigma k_{Hi})Z_c=F_c+F_z-(\Sigma k_{vi})h_v+(\Sigma k_{Hi})H_1-(\Sigma k_{Hi})h_H \quad (3)$$

$$(I_v+I_H)\frac{d^2\theta}{dt^2}+(\Sigma k_{vi}x_{vi}^2+\Sigma k_{Hi}x_{Hi}^2)\theta=M_c+M_z \quad (4)$$

把阀片分为正吹区间A_z、偏吹区间A_c两部分，正吹区间如图2 COD的右部，偏吹区间为COD的左部，则

$$F_z=\iint_{A_z}\beta(P_s-P)dA_p$$

$$M_z=\iint_{A_z}\beta(P_s-P)x\,dA_p$$

偏吹区间内，假设气阀各部分两侧压力相等，则偏吹区间气缸侧压力可写为

$$P_c=P+\frac{\xi\upsilon_s}{2(\frac{P}{P_s})^{\frac{1}{K}}}\left(\frac{dm_c}{dt}\,\frac{1}{A_c}\right)^2$$

式中　ξ——气流从偏吹区间流入气缸时的阻力系数；

A_c——偏吹区间气缸入口处面积，$A_c\doteq D_cL$，如图1、2所示。

$$F_c=\iint_{A_c}\beta(P_s-P_c)dA_p$$

$$M_c=\iint_{A_c}\beta(P_s-P_c)xdA_p$$

式中推力系数 β 是阀片位移的函数[1]，阀片各点位移 Z 为

$$Z=Z_c+\theta x$$

考虑压缩介质为理想气体，假设流过气阀的气流为一维、稳定、绝热流，因此可得如下能量守恒方程[2]：

$$\frac{dP}{dt}+\frac{KP}{V}\frac{dV}{dt}-\frac{KP_s\upsilon_s}{V}\frac{dm}{dt}=0 \qquad (5)$$

式中 V 为气缸工作容积，盖侧时：

$$V=V_h\left(\varepsilon+\frac{1-\cos\gamma}{2}+\frac{\lambda}{4}\sin^2\gamma\right)$$

$$\frac{dV}{dt}=\omega V_h\left(\frac{\sin\gamma}{2}+\frac{\lambda}{4}\sin 2\gamma\right)$$

m 为流过气阀的总质量，由连续性方程可得[2]

$$\left.\begin{aligned}&\frac{dm}{dt}=\frac{dm_c}{dt}+\frac{dm_z}{dt}\\&\frac{dm_z}{dt}=\frac{NA_{efz}}{\upsilon_s}\left(\frac{P}{P_s}\right)^{\frac{1}{K}}\sqrt{\frac{2KRT_s}{K-1}\left[1-\left(\frac{P}{P_s}\right)^{\frac{K-1}{K}}\right]}\\&\frac{dm_c}{dt}=\frac{NA_{efc}}{\upsilon_s}\left(\frac{P}{P_s}\right)^{\frac{1}{K}}\sqrt{\frac{2KRT_s}{K-1}\left[1-\left(\frac{P}{P_s}\right)^{\frac{K-1}{K}}\right]}\end{aligned}\right\} \qquad (6)$$

其中

$$A_{efz}=\iint_{A_z}\alpha\, dA_g$$

把气流流过偏吹区当作两个节流系统串联，其相应的有效通流面积：[2]

$$A_1=\frac{1}{\sqrt{\xi}}D_cL$$

$$A_2=\iint_{A_c}\alpha\, dA_g$$

则

$$A_{efc}=\frac{A_1A_2}{\sqrt{A_1^2+A_2^2}}$$

式中流量系数 α 为阀片位移的函数，可通过气阀吹风试验确定，也可参考文献[3]。

气阀刚开启时，气缸内压力 P_e 可由阀片所受气体力与阀片弹簧力相等这一关系求得，根据气体膨胀过程方程及活塞运动方程可求得气阀开启角 γ_e，故可得如下初始条件：

$$\left\{\begin{aligned}&\gamma_0=\gamma_e\\&P_0=P_e\\&Z_{c0}=0\\&\dot{Z}_{c0}=0\\&\theta_0=0\\&\dot{\theta}_{c0}=0\\&m_{c0}=0\\&m_{z0}=0\end{aligned}\right. \qquad (7)$$

考虑阀片倾侧运动的幅度很小，当阀片与缓冲片碰撞时，假设这一过程瞬时完成，碰撞后阀片与缓冲片一起运动[4]，由动量方程及动量矩方程可得

$$Z_{c\,i+1}=H_1 \qquad (8)$$

$$\dot{Z}_{c\,i+1}=\frac{m_v}{m_H+m_v}\dot{Z}_{ci} \qquad (9)$$

$$\dot{\theta}_{i+1}=\frac{I_v}{I_H+I_v}\dot{\theta}_i \qquad (10)$$

考虑碰撞过程中势能守恒，则

$$\theta_{i+1}=\sqrt{\frac{\Sigma k_{vi}x_{vi}^2}{\Sigma k_{vi}x_{vi}^2+\Sigma k_{Hi}x_{Hi}^2}}\theta_i \qquad (11)$$

阀片与升程限制器或阀座碰撞时，碰撞点只能是A点或B点，如图2所示，引入一反弹系数C_R，C_R定义为反弹速度值与碰撞速度值之比[4]，则

当A与升程限制器碰撞时，即$Z_c+\theta R_0=H_2$时

$$\dot{Z}_{ci+1}=\frac{-(1+C_R)(\dot{Z}_i+\dot{\theta}_i R_0)(I_H+I_v)}{(m_v+m_H)R_0^2+I_H+I_v}+\dot{Z}_i \quad (12)$$

$$\dot{\theta}_{i+1}=\frac{-(1+C_R)(\dot{Z}_i+\dot{\theta}_i R_0)(m_v+m_H)R_0}{(m_v+m_H)R_0^2+I_H+I_v}+\dot{\theta}_i \quad (13)$$

当B与升程限制器碰撞时，即$Z_c-\theta R_0=H_2$时

$$\dot{Z}_{ci+1}=\frac{-(1+C_R)(\dot{Z}_i-\dot{\theta}_i R_0)(I_H+I_v)}{(m_v+m_H)R_0^2+I_H+I_v}+\dot{Z}_i \quad (14)$$

$$\dot{\theta}_{i+1}=\frac{(1+C_R)(\dot{Z}_i-\dot{\theta}_i R_0)(m_v+m_H)R_0}{(m_v+m_H)R_0^2+I_H+I_v}+\dot{\theta}_i \quad (15)$$

当A与阀座碰撞时，即$Z_c+\theta R_0=0$时

$$\dot{Z}_{ci+1}=\frac{-(1+C_R)(\dot{Z}_i+\dot{\theta}_i R_0)(I_H+I_v)}{(m_H+m_v)R_0^2+I_H+I_v}+\dot{Z}_i \quad (16)$$

$$\dot{\theta}_{i+1}=\frac{-(1+C_R)(\dot{Z}_i+\dot{\theta}_i R_0)(m_H+m_v)R_0}{(m_H+m_v)R_0^2+I_H+I_v}+\dot{\theta}_i \quad (17)$$

当B与阀座碰撞时，即$Z_c-\theta R_0=0$时

$$\dot{Z}_{ci+1}=\frac{-(1+C_R)(\dot{Z}_i-\dot{\theta}_i R_0)(I_H+I_v)}{(m_H+m_v)R_0^2+I_H+I_v}+\dot{Z}_i \quad (18)$$

$$\dot{\theta}_{i+1}=\frac{(1+C_R)(\dot{Z}_i-\dot{\theta}_i R_0)(m_H+m_v)R_0}{(m_H+m_v)R_0^2+I_H+I_v}+\dot{\theta}_i \quad (19)$$

式中R_0为A与B所处圆的半径，如图2所示。

运动方程(1)—(4)、能量守恒方程(5)、连续性方程(6)、初始条件(7)及边界条件(8)—(19)构成了整个压缩机网状阀倾侧运动数学模型，可采用四阶定步长龙格—库塔法求解[2]，全面分析气阀的性能。

对无摩擦网状阀而言，阀片及缓冲片中心存在弹性环臂，其倾侧运动数学模型中，运动方程、初始条件及边界条件均需考虑弹性环臂的影响。

2 实验

把L2—10/8空压机一级吸气阀换装成无摩擦带缓冲片网状阀，气阀采用塞尺检测，保证升程限制器平面与阀座的平行度。气阀在压缩机中如图1所示安放，阀片有4圈，在气阀中按图2所示对称放置。采用图4所示实验装置，测得额定工况下阀片如图2所示A、B及C处的运动规律见图5—7。

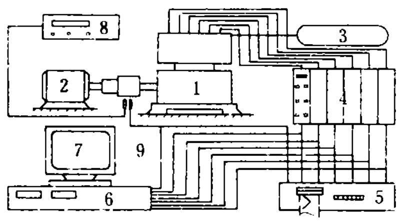

图4 网状阀倾侧运动规律测试装置

1——L2—10/8空压机；2——电机；3——储气罐；4——动态电阻应变仪；5——光线示波器；6——PC—Lab Card数据采集系统；7——显示器；8——转速表；9——活塞止点信号

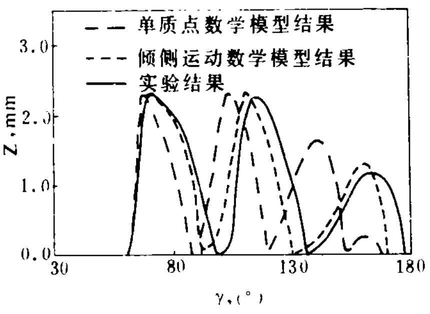

图5 网状阀片A点的运动规律

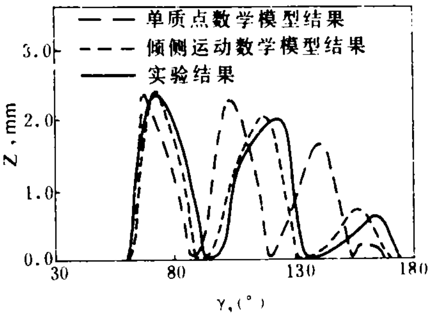

图6 网状阀片 B 点的运动规律

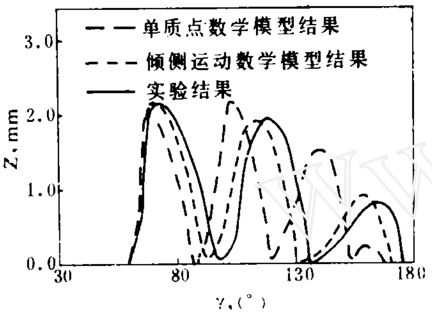

图7 网状阀片 C 点的运动规律

3 结果分析

把压缩机网状阀的运动规律看作平动和转动的复合运动，建立如上网状阀倾侧运动数学模型，可得网状阀片各点的运动规律。把阀片看作仅有一维平动的单质点，建立网状阀单质点数学模型，也可得阀片的运动规律。由单质点数学模型及倾侧运动数学模型得到的 L2—10/8空压机一级吸气阀如图2所示 A、B 及 C 3点的运动规律见图5—7。

由图5—7可看出，网状阀倾侧运动数学模型能比单质点数学模型更精确地反映网状阀的真实运动规律。

由于网状阀片处于倾侧运动状态，在靠止点附近并未完全关闭，因此气缸内与阀腔间压力差仍维持较小状态，阀片在靠止点附近时，不会象单质点数学模型所得的结果一样，重新开启。

由倾侧运动数学模型得到的阀片与升程限制器的最大碰撞速度比单质点数学模型要大得多，且发生在阀片第二次 B 点与升程限制器碰撞时，这是由于第一次 A 点与升程限制器碰撞时，产生了很高的角加速度。

当倾侧幅度较小时，阀片与升程限制器碰撞的速度小且次数也少。气阀设计时，把弹簧分布在网状阀片的外圈，提高 $\Sigma k_{vi} x_{vi}^2$，可减小阀片倾侧运动的幅度。

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ABSTRACTS

Experimental investigation of flowfields of EPVC- Ⅱ type cyclone tubes. Liu Guorong, Ji Zhongli, Jin Youhai, Shi Mingxian (University of Petroleum, Dongying, Shandong, China) ······ (249)

The flowfields of EPVC- Ⅱ type cyclone tubes were measured by using a five-hole pilot tube, the influence of the height of separation space, the structure of ash handling equipment, and the parameters at outlet of vanes on flowfields was discussed, a cyclone shielding phenomenon of rotational flow at dust exit was discovered, a proper structure size was summarized, and the calculating formulae of tangential velocity were obtained with regression.

Key Words: Cyclone Tube, Flowfield, Cyclone Shelding

Experimental investigation of heat transfer characteristics of float head waste heat boilers. Wang Yanpeng, Wang Shisheng, Yang Tianliang, Zhang Xiaopeng, Zhou Yuming (Xian Jiaotong University, Xian, Shanxi, China) ······ (253)

A large proportional experiment model (M 1 : 2) of float head waste boilers was established, and the relations between the average convection heat release factors of air sides at the down radiation section, the up radiation section, and the convection section of a waste heat boiler model and Reynolds number and Prandtl number were measured by using cool air as imitate medium, hot water as a heat source of heat exchange, many data and calculations of the average heat exchange factors at each section were derived. The calculations had a better agreement with the experimental data.

Key Words: Float Waste Heat Boiler, Heat Transfer Characteristics

A study of dynamic membrane filters of complicated mixing liquids and their membrane filtration speeds. Wang Xiaojing, Jin Dingwu (Tianjin University, Tianjin, China) ······ (259)

The form, influence factors, and changing laws of membrane filtration resistance of rotating vane dynamic membrane filters in membrane filtration process of complicated mixing liquids were analysed based on resistance theory, a mathematical model suitable to describe membrane filtration speeds of complicated mixing liquids was established through membrane filtration experiments, a new way was provided for separation, clarification, and concentration of complicated mixingl iquids in industry.

Key Words: Rotating Vane Dynamic Membrane Filter, Membrane Filtration Speed

A study of mixing performance of new spouting granular material mixers. Chen Yinfei, Ge Zhonghua (Zhejiang University of Technology, Hangzhou, Zhejiang, China) Jin Yong, Yu Zhiqing, qinghua university, Beijing, China) ······ (263)

The retention time distribution and mixing degrees of a new spouting granular material mixers were measured, the mixing membrane and major causes of raising mixing degree after gas current impact were analysed, and a comparison was made with other mixers. The results showed that the mixing degree of new spouting mixers could reach 0.94, and they were more suitable for granular materials with great property difference.

Key Words: Granular Material, Mixing Performance, Mixer

Research of Ni-base cast alloy with corrosion resistance in $HCl + FeCl_3$ medium. Qin Zirui, Li Longsheng (Dalian University of Technology, Dalian, Liaoning, China) Yu Yong, Liu Dejing (Dalian Acid-Resistant Pump Plant, Dalian, Liaoning, China) ······ (266)

The chemical compositions of Ni-base cast alloy for $HCl + FeCl_3$ medium were designed, the metallographic compositions and fracture faces of the alloy were observed by using metallographic microscopes and SEM, the influence of various heat treatments on the alloy property were studied. The results showed that the compound action of lower contents of iron and higher contents of chromium, nickel, molybdenum made the alloy have a corrosion resistance, a higher pitting resistance, a satisfactory cast property, and a comprehensive mechanical property in $HCl + FeCl_3$ medium. The heat treatment of the alloy showed that proper heat treatment was $1\,250 \pm 10$ C of heating temperature, and solid solution treatment with water cooling after 1h constant temperature.

Key Words: Metallographic Composition, Chemical Composition, Corrosion Resistance, Casting Property, Mechanical Property

A study of leaning motion of plate valves of reciprocating compressors. Pan Shulin, Lin Mei, Shu Pengcheng (Xian Jiaotong University, Xian Shanxi, China) ······ (272)

A mathematical model of leaning motion caused by air off-blowing was established by taking the motion of plate valves of reciprocating compressors as compound motion, and taking a plate valve with a damping plate which was deviously installed at the section of the cylinder as an example, and a verification was obtained with experiments. Finally, the result was compared with that of single particle mathematical model of the valve plate.

Key Words: Reciprocating Compressor, Plate Valve, Leaning Motion

Viscoelastic characteristics of a gland packing and its effect on seal performance. Hao Muming, Gu Yongouan (University of Petroleum, Dongying, Shandong, China) ························ (277)

The viscoelastic characteristics of gland packings were analysed, a mechanical model describing the viscoelastic characteristics was established, the changing features of the viscoelastic characteristics of the gland packings in a dynamic working condition were further discussed, the critical vibration frequency ω_c which had an effect on seal reliability and the maximum phase retardation tg$\varnothing_{max}$ were derived, and a reliability analysis was made of packing seal in a dynamic condition.

Key Words: Gland Packing, Viscoelastic Characteristic, Mechanic Model, Critical Vibration Frequency, Maximum Phase Retardation, Reliability

Development of high pressure reactor of aluminum without horizontal weld seams for concentrated nitric acid. Wang Zhensheng, Feng Chungui, Du Wenlong, Cui Decai, Xing Jifeng (Beijing General Research Institute of Non-Ferrous Metals, Beijing, China) ························ (283)

The fabrication technology of high pressure reactor of aluminium without horizontal weld seams for nitric acid was presented. The influence of materials, casting quality, deformation rate, procedure arrangement, and heating temperature on corrosion resistance of cylinders was discussed, and a comparison was made of the use effects between cylinders without seams and cylinders with seams.

Key Words: High Pessure Reactor, Fabrication Technology, Corrosion Resistance

Design and application of new type Ventri dust removers. Liu Guangwen (Shenyang Res. Inst of Chem. Tech, Shenyang, Liaoning, China) ························ (287)

The charadteristics, structure, working principles, design calculations and application of a new type Ventri dust remover were presented for the reference of production and design.

Key Words: Ventri Dust Remover, Design, Application

Analyses and controls of deformation of the equatorial plate and the top crown of a spherical tank after weld. Wang Zhiqang (Zhongyuan Petrochemical United Corporation, Puyang, Henan. China) ························ (290)

The causes were analysed of the over standard of curvity deviation of the equatoriat plate and the top crown after weld in a thin-wall spherical tank, and some control methods and suggestions were proposed with practical production.

Key Words: Spherical Vessel, Deformation After Weld, Control Method

A new method for measuring creep damage distribution of furnace tubes. Ma Gongxun (Nanjing University of Chemical Technology, Nanjing, Jiangsu, China) ······ (294)

Based on free vibration theory of bending of thin sheet deformation, the basic frequencies fo cantilever sheets and cantilever sheets with concentrated mass were calculated numerically by using difference method, the relations between basic frequencies were derived, the method using an accelerometer to measure the elastic modulus of the materials of furnace tubes was given, the radial distribution of creep damages of furnace tubes was determined. The results had a good agreement with the results fo ultrasonic flaw detection.

Key Words: Frequency, Elastic Modulus, Furnace Tube, Creep Damage

Improvements of pneumatic structure of forming machines for manpower vehicle tyres. Wang Aiguo (Dandong Chemical Machinery Share Co Ltd, Dandong, Liaoning, China) ························ (299)

Kdy Words: Forming Machine of Manpower Vehicle Tyre, Pneumatic Structure, Improvement

Biocides for controlling microbes in cooling water systems. Zhou Bensheng (Nanjing University of Chemical Technology, Nanjing, Jiangsu, Chena) ·················· (301)

The performance, characteristics, and development trends of additives for controlling microbes in cooling water systems, such as oxidative biocides non-oxidative biocides were simply presented.

Key Words: Cooling Water, Biocide, Oxidation, Non-Oxidation