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A Dynamic Responding Characteristic Non-linear Analyzing Method of Cryogenic Valve

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Abstract—**To reduce the dynamic responding time of cryogenic valve, and improve the reliability and security of cryogenic valve, depending on the operation principle of cryogenic valve, a dynamic responding transferring non-linear function and dynamic responding model of cryogenic valve were built based on kinetics theory. Afterwards, by means of Runge-Kutta solution method, a dynamic recursive four stages Runge-Kutta solution method was constructed by the introducing of changed step length coefficient and oblivion coefficient. Finally, this method was demonstrated and validated by a sample. Consequently, this method has provide a support for reducing dynamic responding time of cryogenic valve, and has provide an approach to rationally and exactly evaluating reliability and security of cryogenic valve.**

Keywords- dynamic responding; Runge-Kutta; non-linear: cryogenic valve

I. INTRODUCTION

Because start-up process of cryogenic valve is influenced by heat preservation, airproof, flow, construction, is influenced by switch delay, damp, medium pressure's non-linear characteristics, airproof force, and is influenced by asymmetry clearance force, friction non-linear libration source, and so on, there is non-linear characteristic in the dynamic responding process of cryogenic valve. To this non-linear characteristic in the dynamic responding process of cryogenic valve, all non-linear factors have been always ignored in practice, or only a few non-linear characteristics have been considered in traditional linear analyzing method, so that a lot of important information is neglected[1-2].

Consequently, there is a great gap between analyzing result and true dynamic responding characteristic of cryogenic valve, for example flow resistance error, valve core displacement error, interval flow error. When dynamic responding characteristic is analyzed in cryogenic system (such as Liquefied Natural Gas, liquid-oxygen, liquid-oxygen), there may be a pressure libration or flow fluctuate, and may induce the acute libration of cryogenic system. Finally, cryogenic system may appear pipeline leakage, blowout, malfunction, even personnel or equipment may be damaged.

There were some researches of dynamic responding characteristic analyzing aspects of cryogenic valve[3-7]. However, few studies have been devoted to dynamic responding characteristic non-linear analyzing of cryogenic valve. Furthermore, few researches have investigated in dynamic responding characteristic non-linear analyzing of cryogenic valve by particle swarm dynamic recursive four stages Runge-Kutta.

For highly increase the start-up and ending velocity of cryogenic valve, dynamic responding characteristic of cryogenic valve should be researched by non-linear analyzing method to meet reliability and security demand of cryogenic valve, and to reduce the dynamic responding time of cryogenic valve. This research will adapt to the development of cryogenic system, will satisfy reliability and security need of cryogenic system, for example Liquefied Natural Gas station, the cryogenic drive engineering of spaceflight.

To reduce the dynamic responding time of cryogenic valve, and improve the reliability and security of cryogenic valve, depending on the operation principle of cryogenic valve, a dynamic responding non-linear transferring function and dynamic responding model of cryogenic valve were built based on kinetics theory. Afterwards, by means of Runge-Kutta solution method, a dynamic recursive four stages Runge-Kutta solution method was constructed by the introducing of changed step length coefficient and oblivion coefficient. Finally, this method has provide a support for reducing dynamic responding time of cryogenic valve, and has provide an approach to rationally and exactly evaluating reliability and security of cryogenic valve.

II. THE DYNAMIC RESPONDING MODEL OF CRYOGENIC VALVE

An operation principle of cryogenic valve is shown in Figure 1. When electro-valve is electrified, electro-valve centre is opened and manipulation air is put in air cylinder. The pressure of manipulation air will get over the rigidity of spring, the friction force of airproof, the action force of medium, and so on. Afterwards, the piston is droved by pressure of manipulation air to drive the movement of valve centre. Finally, this cryogenic valve is opened. On the other hand, when electro-valve is not electrified, electro-valve is closed and manipulation air is not put in air cylinder. This spring will replaced by the rigidity of spring to get over the friction force of airproof, the action force of medium, and so on. Afterwards, the piston is droved by the rigidity of spring to drive the movement of valve centre. Finally, this cryogenic valve is closed.

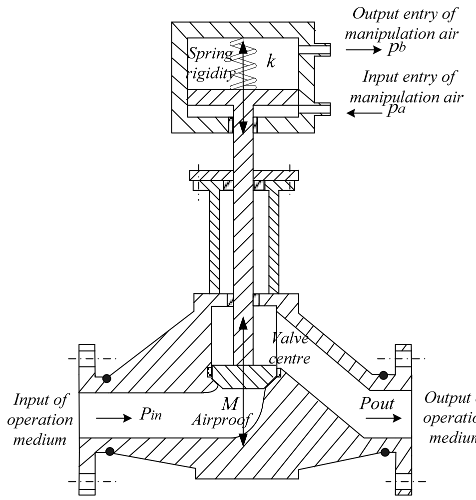


Figure 1. A sample function principle of cryogenic valve

The dynamic responding model of cryogenic valve is constructed by the kinetics movement process of valve centre. The operation forces of valve centre include fluid operation force and elasticity component operation force. If the instant fluid operation force is ignored, the operation forces of valve centre are mainly from magnetic operation force, fluid stillness force, stable fluid operation force, the damp force of gap, and spring operation force, inertia operation force. Consequently, the operation force equation of valve centre in cryogenic valve is as following:

$$M\frac{d^2x}{dt^2} = F_k - F_i - F_j - F_z - F_g \qquad (1)$$

Where *M* is the quality of valve centre, *x* is the movement of valve centre, F_k is stable air operation force of piston, F_i is the operation force of transportation medium, F_j is stable fluid operation force, F_z is the damp force of gap, and F_g is spring operation force.

The dynamic responding process of cryogenic valve is expressed as following:

$$\begin{aligned} M\frac{d^2x}{dt^2} = {} & (P_aA_a - P_bA_b - 2C_d'\omega'\Delta y'(P_a - P_b)\cos\theta' + \\ & \rho'Q_b'V_2') - (P_{in}B_a - P_{out}B_b) - (2C_d\omega\Delta x(P_{in} - \\ & P_{out})\cos\theta - \rho Q_bV_2) - (\frac{\pi d_z lu}{h}\cdot\frac{dx}{dt}) - (K_sx + K_sx_0) \end{aligned} \qquad (2)$$

The dynamic responding non-linear transferring function of cryogenic valve is shown as following:

$$Y = \frac{K_1 + K_3}{Ms^2 + K_2s + K_4} \qquad (3)$$

Where $K_1 = (P_aA_a - P_bA_b - 2C_d'\omega'\Delta y'(P_a - P_b)\cos\theta' + \rho'Q_b'V_2') - (P_{in}B_a - P_{out}B_b)$

$$K_2 = \frac{\pi d_z lu}{h} \quad K_3 = \rho Q_bV_2 - K_sx_0$$

$$K_4 = 2C_d\omega\,(P_{in} - P_{out})\cos\theta + K_s$$

This dynamic responding transferring function of cryogenic valve is a non-linear dynamic responding process. If this dynamic responding transferring function of cryogenic valve is solved by common linear method (multidimensional interpolation or series solving function approach), the result may has a great error and will not ideally accord with practicality engineering need. As a result, there need a new non-linear solving method to solve dynamic responding transferring function of cryogenic valve for highly decreasing error, improving precision, and ideally accord with practicality engineering need.

III. The Dynamic Recursive Four Stages Runge-Kutta Solution Method

Aim to non-linear dynamic responding problem, a directness and precision math solving model is often difficulty in construction. Even if this model is constructed, there need a lot of parameters to validate. The non-linear dynamic responding problem is restricted by the lots of calculation quantity and high error of traditional non-linear solving method. For solving non-linear dynamic responding problem of cryogenic valve, a new non-linear solving method based on is established by based on kinetics theory and four stages Runge-Kutta solution method.

Runge-Kutta methods are an important family of implicit and explicit iterative methods for the approximation of solutions of ordinary different equation. There techniques were developed by the German mathematician's C .Runge and M. W. Kutta [8-9]. The solving process of four stages Runge-Kutta solution method is as following:

$$y_{k+1} = y_k + \sum_{i=1}^{N} c_iK_i \qquad (4)$$

Where $K_i = hf(x_k, y_k)$, $K_i = hf(x_k + a, h, y_k + \sum_{j=1}^{i-1}\beta_{ij}K_j)$, $i = 2, 3, \cdots n$. If there is *N*=4, this formula is turn to four stages Runge-Kutta solution method[10].

$$\begin{aligned} y_{k+1} &= y_k + \frac{h}{6}(K_1 + 2K_2 + 2K_3 + K_4) \\ K_1 &= f(x_k, y_k) \\ K_2 &= f(x_k + \frac{h}{2}, y_k + h\frac{K_1}{2}) \\ K_3 &= f(x_k + \frac{h}{2}, y_k + h\frac{K_2}{2}) \\ K_4 &= f(x_k + \frac{h}{2}, y_k + hK_3) \end{aligned} \qquad (5)$$

The numerical valve integral curve chart of four stages Runge-Kutta solution method is expressed in Figure 2. The point *A*, *B* and *C's* coordination in integral function $y=f(x)$ respectively are(x_A, $f(x_A)$), (x_B, $f(x_B)$), (x_C, $f(x_C)$), and these slopes respectively are K_A, K_B, and K_C in Figure 2.

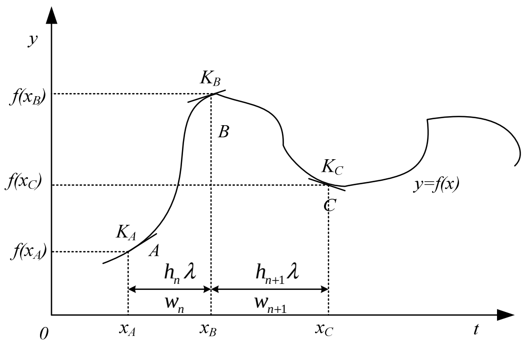


Figure 2. The numerical valve integral curve chart of four stages Runge-Kutta solution method

Because every step need calculate error to adjust step and integral step h is decided by error magnitude of output y_n, there are a great deal calculation quantity and high errors. As a result, changed step length coefficient and oblivion coefficient are introduced for improving precision and decreasing calculation quantity.

This oblivion coefficient is set as λ, and there is:

$$\lambda = [0.5, 1, 2] \begin{cases} E_n > E_{\max}, & \lambda = 0.5 \\ E_n = E_{\max}, & \lambda = 1 \\ E_n < E_{\min}, & \lambda = 2 \end{cases} \tag{6}$$

Where E_n is local truncation error the output of $y_{n.,}$ and there is $E_n = (2k_1 - 9k_3 + 8k_4 - k_5)\ h/30$. $E_{\min}$and $E_{\max}$ respectively is maximum error and minimum error. When there is λ =1, Runge-Kutta is a changeless step Runge-Kutta solution method.

w_n is set as the weight coefficient of nth step, and it is:

$$w_n = h_{n-1}/h_n \dots w_{n+2} = w_n \cdot w_{n+1} \tag{7}$$

By means of this weight coefficient, the influence from former error to behind error can be considered to enhance the relation among steps. Changed step length *h of* Runge-Kutta is defined as:

$$h_{n+1} = w_{n+1} h_n \lambda \tag{8}$$

Where h is the step length of nth step.

The dynamic recursive four stages Runge-Kutta solution method is constructed by changed step length *h.*

$$\begin{aligned} K_1 &= f(x_k,\ y_k) \\ K_2 &= f(x_k + \frac{h_n}{2},\ y_k + h_n \frac{K_1}{2}) \\ K_3 &= f(x_k + \frac{h_n}{2},\ y_k + h_n \frac{K_2}{2}) \\ K_4 &= f(x_k + \frac{h_n}{2},\ y_k + h_n K_3) \end{aligned} \tag{9}$$

By means of the introducing of oblivion coefficient, this dynamic recursive four stages Runge-Kutta solution method can establish a changed step length strategy and to decrease error in a great deal calculation quantity. At the same time, by means of the definition of changed step length, this dynamic recursive four stages Runge-Kutta solution method can consider the influence from former error to behind error to decrease rounding error. Consequently, this dynamic recursive four stages Runge-Kutta solution method can highly reduce calculation quantity, improve solving precision, and ideally accord with practicality engineering need.

IV. APPLICATION

Taking a cryogenic valve as sample, the non-linear dynamic responding characteristic of cryogenic valve is analyzed by the dynamic recursive four stages Runge-Kutta solution method to research the influencing of main factors and to establish amending measure in dynamic responding process of cryogenic valve. The main function parameters of this cryogenic valve are shown in Table. I.

TABLE I. THE MAIN FUNCTION PARAMETERS OF THIS CRYOGENIC VALVE

Operation parameter	**Value**	**Operation parameter**	**Value**
density of transportation medium /kg/m^3	840	quality of valve centre /kg	3.2
output pressure of transportation medium /MPa	0.1	diameter of valve input /mm	65
input pressure of transportation medium /MPa	30	damp hole diameter of valve centre /mm	0.8
velocity coefficient of throttle position	0.99	the rigidity of spring /N/mm	7.6
the inlet angle /(°)	69	interval width of valve /mm	0.02
the pressure of manipulation air /MPa	5	flow coefficient of throttle position	0.62
quality of Spring /kg	0.5	pre-compress value of spring/mm	1.6
cubage of operation air cylinderm/mm^3	7250	the type of manipulation air	He

This non-linear dynamic responding characteristic analyzing procedure of cryogenic valve main includes:

(1) A dynamic responding non-linear transferring function of cryogenic valve has been built:

$$Y = \frac{39250}{3.2s^2 + 297s + 29500}$$

(2) A dynamic responding transferring function of cryogenic valve has been solved by the dynamic recursive four stages Runge-Kutta solution method:

$$x(t) = 1.159941 \sin t - 0.10004 \sin(3t)$$

(3) The non-linear dynamic responding characteristic analyzing of cryogenic valve.

This non-linear dynamic responding process of cryogenic valve is expressed as Figure 4. By means of the solving result of the dynamic recursive four stages Runge-Kutta solution method, the valve start-up characteristic of main influencing factors (the pressure of manipulation air and the rigidity of spring) have been compared and analyzed as Figure 5.

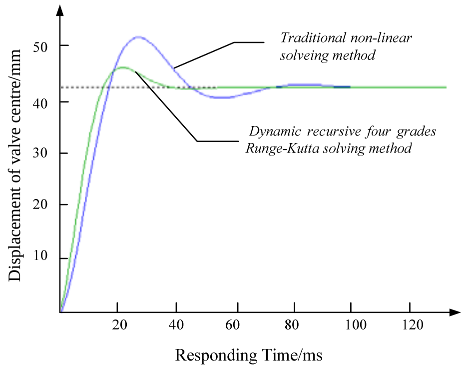
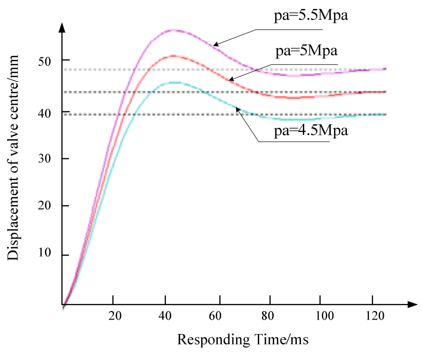
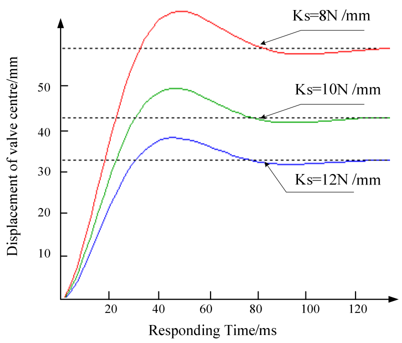


Figure 4. This non-linear dynamic responding process of cryogenic valve



(a)



(b)

Figure 5. The valve opening characteristic of main influencing factors

Based on Figure 4 (a) and (b), the start-up time of cryogenic valve needs approximate 17ms. After start-up, there is a secondary fluctuating and this fluctuating will weaken as time changing. As valve opening, the inlet angle （$\cos\theta, 0 \le \theta \le 90^0$） will increase and stable fluid flow force will weaken to nil. The valve centre will keep a changeless position by means of the pressure of manipulation air. Based on Figure 5, the valve start-up velocity will improved as the increase of the pressure of manipulation air and the decrease of the rigidity of spring.

V. Conclusion

In this paper, a dynamic responding non-linear transferring function and dynamic responding model of cryogenic valve are built based on kinetics theory and operation principle of cryogenic valve at first. Secondly, the dynamic recursive four stages Runge-Kutta solution method by means of the introducing of changed step coefficient and oblivion coefficient for solving non-linear dynamic responding transferring function of cryogenic valve. Finally, this method was demonstrated and validated by a sample. Consequently, this method has provide a support for reducing dynamic responding time of cryogenic valve, improving the reliability and security of cryogenic valve, and has provide an approach to impersonally and exactly evaluating reliability and security of cryogenic valve.

References

[1] K. Liu, and Y. Zhang, “A study on versatile simulation of liquid propellant rocket engine systems transients,” AIAA 2000-3771

[2] A. Peter, A. Hosangadi. and V. Ahuja, “Transient simulations of valve motion in cryogenic systems,”American Institute of Aeronautics and Astronautics, pp. 1-10,2009.

[3] S. Liu and B. Yao, “Adaptive robust control of programmable valves with manufacturer supplied flow mapping only,” The 43rd IEEE Conference on Decision and Control December, vol. 14-17, pp. 1117-1122, 2004.

[4] E. uzunhisarcikli, “Nonlinear dynamic analysis of mitral valve doppler signals: surrogate data analysis,” Turk J Elec Eng & Comp Sci, vol.18(2), pp.327-337, 2010.

[5] C. S. Ritter, A. C. Valdiero, P. L.Andrighetto, F. Zago, “Nonlinear characteristics systematic study in pneumatic actators,” ABCM Symposium Series in Mechatronics, vol. 4, pp. 818-826, 2010.

[6] A. C. Valdiero, D. Bavaresco, P. L. Andrighetto, “Experimental identification of the dead zone in proportional directional pneumatic valves,” International Journal of Fluid Power, vol. 9, pp.27-34,2008.

[7] Z. Rao, G. M. Bone, “Nonlinear modeling and control of servo pneumatic actuators control systems technology,” IEEE Transactions on Control System Technology, vol.16(3), pp.562-569, 2008.

[8] S. Zhang, Z. Deng, W. Li, “Aprecise Rutta-Kutta integration and its application for solv in gnonlinear dynamical systems,” Applied Mathematics and Com-putation, vol.184, pp.496- 502, 2007.

[9] S. Gottlieb, “On high order strong stability preserving Runge-Kutta and multi-step time discretization,”Journal of Scientifics Computation, vol.25, pp.105-128, 2005.