Fuel Oil Dynamic Flow Standard Device and Its Application

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Abstract: This paper introduced a piston-type dynamic flow standard device and the method for applying step flow rate to the turbine flowmeter. seting up math model of the turbine flowmeter and analyzing the dynamic parameter (step response time constant)and things that affect dynamic performance of the flowmeter in theory. acquiring the step flow response data of the flowmeter by experiment and calculating the time constant . the reality result is consistent with theory.

Keyword: flow standard device; turbine flowmeter; unsteady flow; dynamic characteristic

1. Introduction

In general it is steady flow in the liquid flow measurement field ,so flowmeter is calibrated with the steady flow standard device before it is used. Sometime we can meet unsteady flow such as pulsation flow or transient flow. Measuring unsteady flow needs fast response flowmeter. Turbine flowmeter is with good dynamic response performance. The purpose of this paper is to describe a method for determining the dynamic response performance characteristic of turbine flowmeter and quantify the characteristic and provide a proof for the unsteady flow measurement by turbine flowmeter.

2. Piston-typefuel oil flow standard device

The liquid flow standard device is classified two types according to measurement method: mass-measurement and volume-measurement. Piston-type flow standard device is volume-measurement . the structure of the device is show in figure 1.

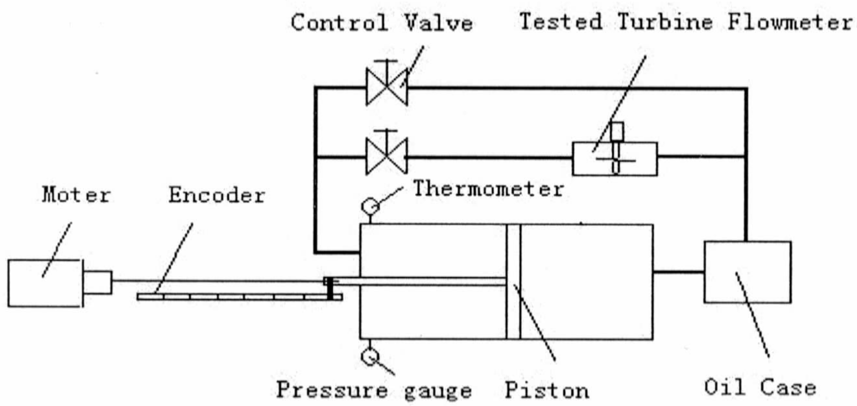

Figure 1 Piston-type flow standard device

it works as follow: the piston of cylinder is drove by a NC server motor to generate flow rate. The flow rate changes with the velocity of the motor. The displacement of the piston is measured with a , encoder. The standard flow rate can be expressed mathematically that

$$q=ALC_TC_P/t \qquad (1)$$

where

q: standard flow rate

A: section area of the piston

L: displacement of the piston

C_P: pressure coefficient of cylinder

t: the measuring time

The oil fluid flow through the flowmeter ,so the error of the meter is acquired ,namely the difference between the output value of the meter and the standard value.

3. Seting up the math model of turbine flowmeter and analyzing its step response

Turbine flowmeter is used widely in industry field, it has some features: broad flow range, good accuracy , good linearity , low pressure decline ,excellent speed of response, low price. The structure of the meter is shown in figure 2.

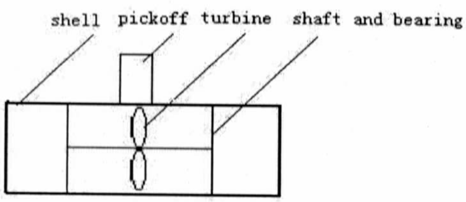

Figure 2 Structure of turbine flowmeter

Operation principle: An external pickoff senses the passing of each rotor blade of the turbine, generating a frequency output. The frequency is directly proportional to the velocity of the fluid, and since the flow passage is fixed, the rotational speed of the turbine is true representation of the volumetric rate of fluid flowing through the flowmeter. It can be expressed mathematically that

$$q=f/K \qquad (2)$$

q: the volumetric rate of fluid pass the meter

f: the output frequency of the meter

K: the meter factor

The meter factor can be acquired by calibration using a steady flow standard device. In the regulated flow rate range the linearity of factor reflects the static performance. The measurement accuracy of steady flow lies on the static performance of flowmeter. Measuring unsteady flow needs flowmeter which is with good dynamic performance, that is excellent speed of response.

C_T: temperature coefficient of cylinder

This article research the dynamic performance of turbine flowmeter. Firstly Setting up the method of the flowmeter ,then study the step flow response of it . The movement differential equation of turbine is show mathematically that

$$J\frac{d\omega}{dt}=T_r-T_{rm}-T_{rf}-T_{re} \qquad (3)$$

where

J: rotation inertia of turbine

ω: rotation velocity

T_r: fluid drive force to turbine

T_{rm} : friction resistance to turbine

T_{rf} : fluid resistance to turbine

T_{re} : magnetism resistance to turbine

Both friction resistance to turbine T_{rm} and magnetism resistance to turbine T_{re} is little, so they are ignored. Now analyzing fluid drive force to turbine T_r and fluid resistance to turbine T_{rf}. Figure 3 shows the fluid velocity rate variety when the fluid flow through the turbine.

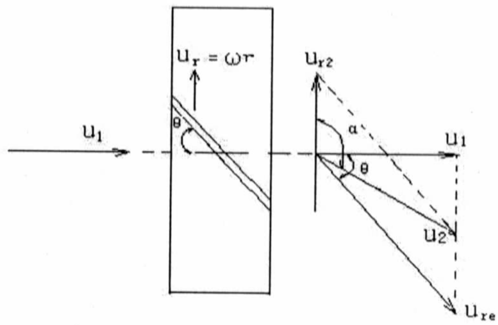

Figure 3 The velocity variety of the fluid and turbine

About figure 3

θ : angle between the blade and the axes

r: the average radius of turbine

ω : the rotation velocity of turbine

u_1: the fluid velocity before turbine

u_2: the fluid velocity behind the turbine

u_{re}: the fluid velocity object to the turbine

According to the impulse theorem and fluid continuum feature, the equation will be acquired as follow:

$$T_r=f_r r=r\rho q\ (u_1\cos 90^o-u_2\cos\alpha) \qquad (4)$$

where

f_r: the force applied to the turbine brim

q: the volume flow rate

ρ : the fluid specific gravity

as well as:

$$u_2 \cos\alpha = u_r - u_1 tg\theta = r\omega - qtg\theta / F \quad (5)$$

where

F: section area of the piston

Summing up equation (4) and equation (5) get the equation as follow:

$$T_r = r\rho q \ (qtg\theta / F - r\omega) \quad (6)$$

The fluid resistance to turbine T_{rf} generally expressed as:

$$T_{rf}=C\rho q^2 \quad (7)$$

Summing up equation (3) , equation (6) and equation (7) and making it simple:

$$\frac{J}{qr^2\rho}\frac{d\omega}{dt} + \omega = \frac{r\rho tg\theta}{F}q \quad (8)$$

The equation (8) tell us the turbine flowmeter is a one-order non-linear system. The motion equation of one-order linear system has the form

Tdc(t)/dt+c(t)=r(t)

C(t): output

R(t): input

The step response of one-order non-linear system is the follow form

$$c(t) = 1 - e^{-\frac{1}{T}t}$$

the parameter T is the only which expresses the system characteristic. When t is equal to T, C(T) is equal to 0.63,T is called the time constant. For turbine flowmeter the T is not a constant ,it changed with the input (q),It is shown that

$T=J/(r^2\rho q)$

The output frequency of turbine flowmeter is expressed as

$$f(t) = f_s(1 - e^{-\frac{1}{T}t})$$

4.The step response test of turbine flowmeter

In general generating directly step flow rate is very difficult. In this paper a special method is used to applying step flow to turbine flowmeter, Figure 4 illustrates it.

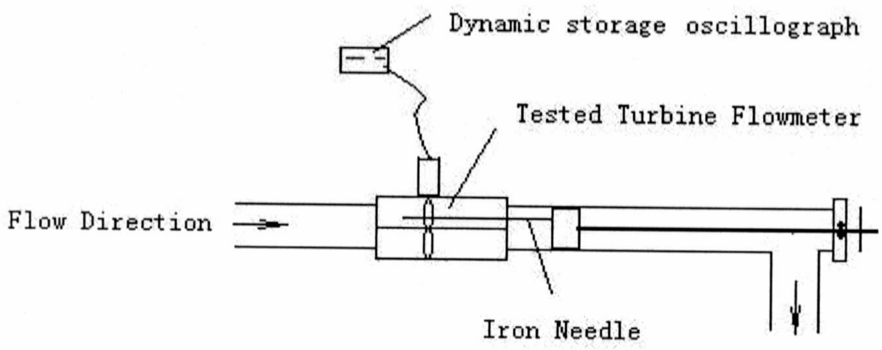

Figure 4 step flow test

The method is base on the mechanism structure of turbine flow meter. A iron needle is insert between two blade of the turbine before the piston flow standard device generate a flow rate. Though the fluid flow steadily through the flowmeter, the turbine can't turn. When starting the test, draw the needle fast, the turbine begins turning. This is equal to applying the flowmeter a step flow. The step flow response data are record by a dynamic storage oscillograph. In this paper a turbine flowmeter which diameter is 25mm is tested. The test data curve is shown as figure 5.

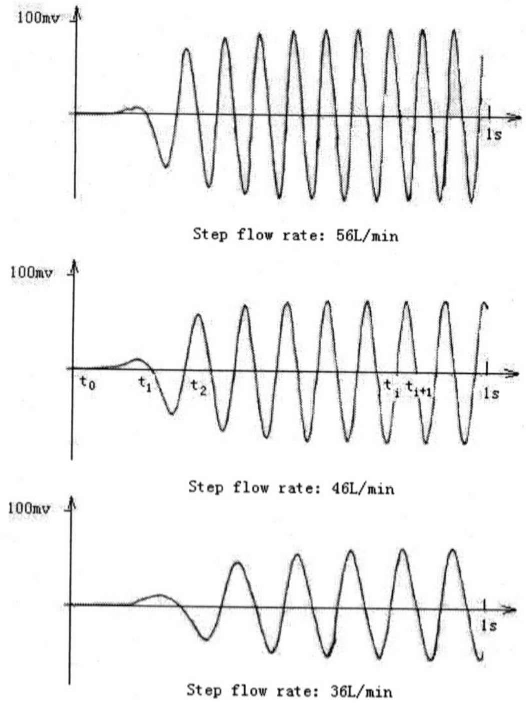

Figure 5 the step flow response curve of turbine flowmeter

The frequency is calculated as follow

$f_0=1/(t_1-t_0)/2$,

$f_1=1/(t_2-t_1)/2$

…

$f_n=1/(t_{n+1}-t_n)/2$

when

$f_{\tau}=0.632f_s$

$\tau_1=25ms$ $\tau_2=33ms$ $\tau_1=41ms$

The frequency-time curve is show as figure 6.

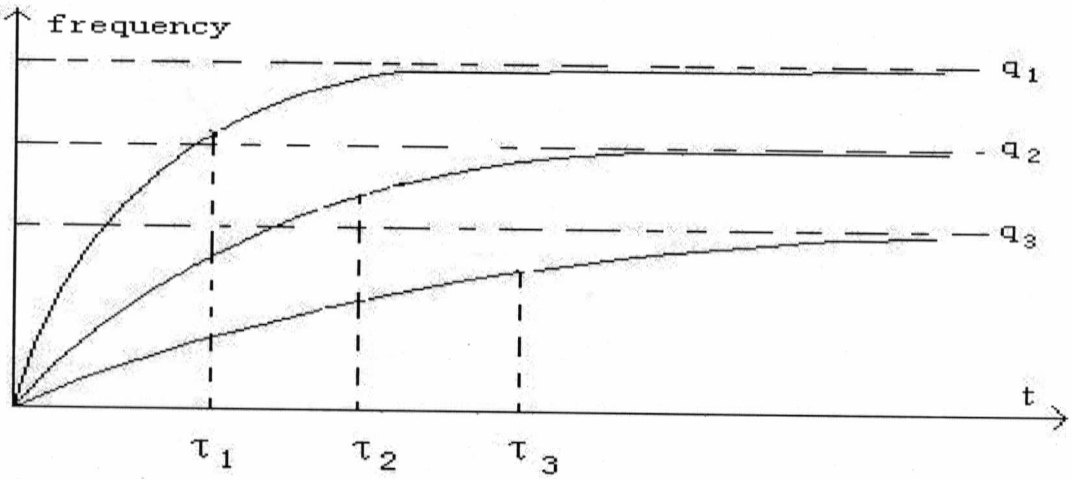

Figure 6 Frequency - time curve

5.conclusion

The turbine flowmeter is a first-order non-linear system, it step flow response speed is mainly relative to the input flow rate, the inertia of the turbine, the radius of the turbine and the specific gravity of the fluid. In this article acquiring the step flow response data of the flowmeter by experiment and calculating the response time. the actual result is consistent with theory.

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