

PRINCIPLE OF CONVERTING THE MECHANICAL MOVEMENTS TO ELECTRICAL SIGNALS BY TURBINE METERS

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Abstract

Turbine meter is a flow measurement device utilizes the angular velocity of rotating blades to measure the flow rate. Pulses for a known time period are counted by turbine meter counting mechanism. The total number of counts for a given time period is proportional to the volumetric flow rate of the turbine meter. National Metrology Institute of Turkey (UME) standard reference turbine meter pulse information is generated by a system called variable reluctance tachogenerator.

This paper explains how mechanical movements of blades are converted to electrical signals and comparing the degree of conformity between the theoretical and experimental results. Meter factor k is utilised to compare experimental and theoretical results. Geometrical calculations and experimental results from the UME reference turbine meter are compared. Vector analysis of the forces acting on the blades showed that blades are moving slower than their geometrically predicted velocity. This is explained by effect of retarding torques on the exit velocity of the fluid

Key words: Turbine meter, rotor, reluctance, magnetic field, retarding torque

1. Introduction

The angular velocity and frequency of rotating blades of a turbine meter are measured by a system based on magnetic circuit. Usually eight or ten ferromagnetic blades on the rotor form a magnetic circuit with the magnet, placed in the housing of the turbine meter [1]. Induced voltage by the magnet coil is a sine wave and its frequency changes proportionally with the angular velocity of the blades. This system is called changing reluctance tachogenerator. The amplitude-modulated sine wave is then passed from a Schmitt trigger and counted by a pulse counter.

2. Magnetic Circuit

It is the electromotive force that enables the current pass from a resistance and flow in an electric circuit (e.m.f). Magnitude of this force is given by the equation;

$$\text{e.m.f} = \text{current} \times \text{resistance}$$

$$\text{e.m.f} = I \times R$$

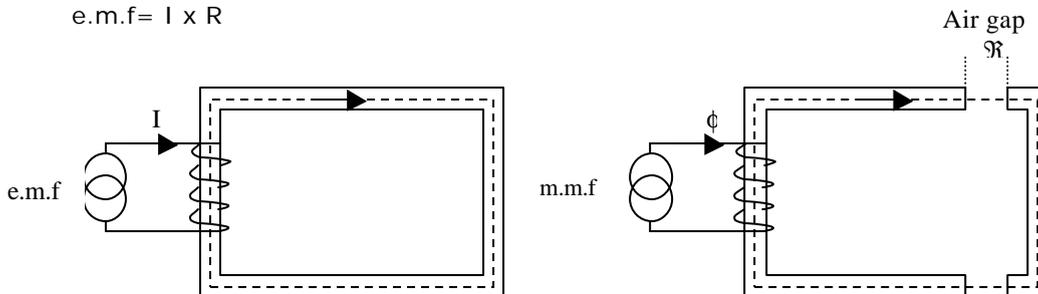


Figure 1

The magnetic circuit drawn above consists a magnet, coil and an air gap. The magnet coil is the source of the magneto motive force (m.m.f) that produces a magnetic flux ϕ in the circuit.

$$\text{m.m.f} = \text{magnetic flux} \times \text{reluctance} = \phi \times \mathfrak{R} \quad (1)$$

Reluctance \mathfrak{R} opposes the magnetic flux in a magnetic circuit just like a resistance does in an electric circuit.

$$\text{In a magnetic circuit } \text{m.m.f.} = nI \quad (2)$$

And the flux is;

$$\phi = nI / \mathfrak{R} \quad (3)$$

This is the flux produced by a single turn of the coil, total flux N is;

$$N = n^2 I / \mathfrak{R} \quad (4)$$

By definition inductance (L) of a coil is the total flux divided by the current;

$$L = N / I = n^2 / \mathfrak{R} \quad (5)$$

this formula tells us that if the reluctance of a circuit is known then the inductance can be calculated.

Reluctance in a magnetic circuit;

$$\mathfrak{R} = S / \mu \mu_0 A \quad (6)$$

where

S ; total path of the magnetic current

μ ; relative permeability of the circuit material

μ_0 ; free space permeability. = $4\pi \times 10^{-7} \text{ H m}^{-1}$

A; Cross sectional area of the magnetic path.

Magnetic circuit in Figure 1 is divided into two pieces by an air gap. Total reluctance is the reluctances of the two pieces and reluctance of the air gap. Since the relative permeability of air is close to unity and that of the core material many thousands, the presence of the air gap causes a large increase in circuit reluctance and a corresponding decrease in flux and inductance. Thus a small variation in air gap causes a measurable change in inductance.

3. Variable Reluctance Tachogenerator

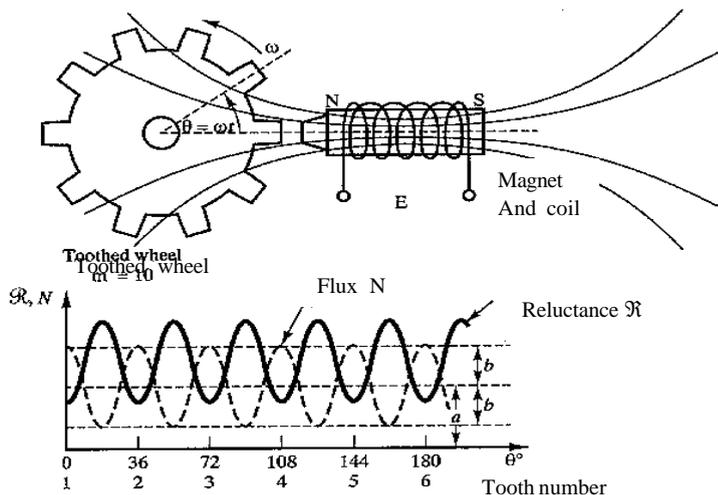


Figure 2

Faraday's law of electromagnetic induction [2] states that if the flux N linked by a conductor is changing with time, then a back e.m.f. is induced in the conductor with a magnitude equal to the rate of change of flux;

$$E = - dN / dt \quad (7)$$

In an electromagnetic element the change in flux is produced by the motion; this means that the induced e.m.f. depends on the linear and angular velocity of the motion. Variable reluctance tachogenerator is the electromagnetic sensor and consists of a tooth wheel of ferromagnetic material that is attached to the rotating shaft and the coil on a permanent magnet, extended by a soft iron pole piece. The wheel moves in close proximity to the pole piece, causing the flux linked by the coil to change with time, thereby inducing an e.m.f in the coil.

The magnitude of the e.m.f. can be calculated by considering the magnetic circuit formed by the permanent magnet, air gap and the wheel. The m.m.f is constant with time and depends on the strength of the permanent magnet. The reluctance of the circuit will depend on the width of the air gap between the wheel and pole piece. When a tooth is close to the pole piece the reluctance is minimum but will increase as the tooth moves away. The reluctance is maximum when a gap is adjacent to the pole piece but falls again as the next tooth approaches the pole piece. Figure 2 shows the variation in reluctance with angular rotation.

Total flux N linked by a coil of n turns is:

$$\phi = \text{m.m.f.} / \mathfrak{R} \quad (8)$$

$$N = n\phi = n \times \text{m.m.f.} / \mathfrak{R} \quad (9)$$

Reluctance minimum corresponds to a flux maximum and vice versa. This relation may be approximated by;

$$N(\theta) \sim a + b \cos m\theta \quad (10)$$

Where a is the mean flux, b is the amplitude of the flux variation and m is the number of teeth.

The induced e.m.f. is;

$$E = - dN / dt \quad (11)$$

$$E = - dN / d\theta \times d\theta / dt \quad (12)$$

$$dN / d\theta = - bm \sin m\theta \quad (13)$$

$$d\theta / dt = \omega_r \text{ (angular velocity of the wheel)}$$

Assuming $\theta=0$ at $t=0$;

$$\theta = \omega_r t \quad (14)$$

Thus;

$$E = bm\omega_r \sin (m\omega_r t) \quad (15)$$

This is a sinusoidal signal of amplitude $bm\omega_r$ and frequency $m\omega_r / (2\pi)$; both amplitude and frequency are proportional the angular velocity of the wheel. A variable reluctance tachogenerator is incorporated in the turbine flow meter to give an accurate measurement of volume flow rate or total volume of fluid.

4. Turbinemeter

The number of rotor cycles per second " f " is proportional to the volume flow rate Q ; $f = KQ$, so that the measurement of " f " yields Q .

Turbine meters [3] are often used to measure the total volume of fluid;

$$V = \int_0^T Q dt \quad (16)$$

The total number of rotor cycles during T is;

$$N = \int_0^T f \, dt = K \int_0^T Q \, dt = KV \quad (17)$$

Total current is proportional to volume.

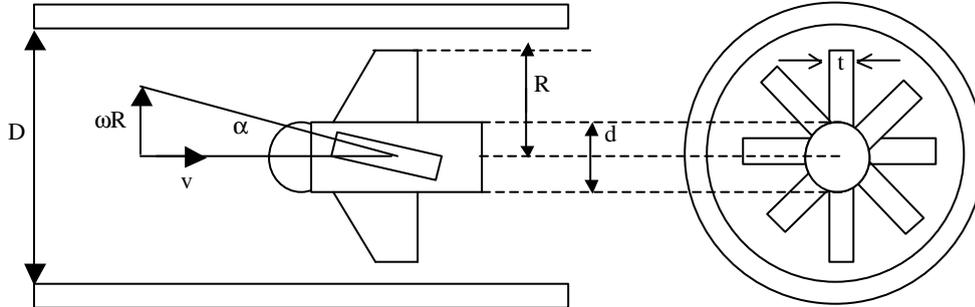


Figure 3

Assuming that the drag torque due to bearing and viscous friction is negligible, the rotor angular velocity ω_r is proportional to Q ;

$$\omega_r = k Q \quad (18)$$

k is a constant which depends on the geometry of the blade system. If Q is the volume flow rate through the meter then the corresponding mean velocity is;

$$V = Q / A \quad (19)$$

where A is the cross sectional area of the fluid. Assuming the fluid fills the pipe then:

$A = \text{Area of the pipe} - \text{Area of hub} - \text{Area of blades}$

$$A = \frac{\pi D^2}{4} - \frac{\pi d^2}{4} - m(R - d/2)t \quad (20)$$

where

m ; is the number of blades

t ; average thickness of blades

From the inlet velocity triangle shown in Figure 3;

$$\frac{\omega_r R}{V} = \tan \alpha \quad (21)$$

Where ω_r is the angular velocity of the blades , $\omega_r R$ is the velocity of the blade tip perpendicular to the direction of flow and α is the inlet blade angle at the tip.

From these equations, k can be found as;

$$k = \frac{\omega_r}{Q}$$

$$k = \frac{\tan \alpha}{AR} \quad (22)$$

k is a constant that can be calculated by design parameters, and the voltage induced in the coil according to the principle of the variable reluctance tachogenerator is:

$$E = bmkQ \sin (mkQt) \quad (23)$$

The flow meter signal is usually passed through an integrator and a Schmitt trigger circuit. The output is constant amplitude, square wave signal of variable frequency f, which can be easily transmitted, to a counter.

6.Comparison Of Theoretical And Experimental Results For Meter Factor “k”

a. Theoretical result for meter factor k

Meter factor k is calculated by using the design parameters (Figure 3); flow meter inside diameter (D), blade radius (R), rotor diameter (d) and blade angle (α) for UME reference turbine meter.

D=0,12 m
 R=0,055 m
 d=0,075 m
 tan α =41°

Equation (12) gives the effective area for fluid flow inside the flow meter;

A=0,006573375 m²

And calculated meter factor k according to equation (14) is;

k =2404,4657

b. Experimental result for meter factor k

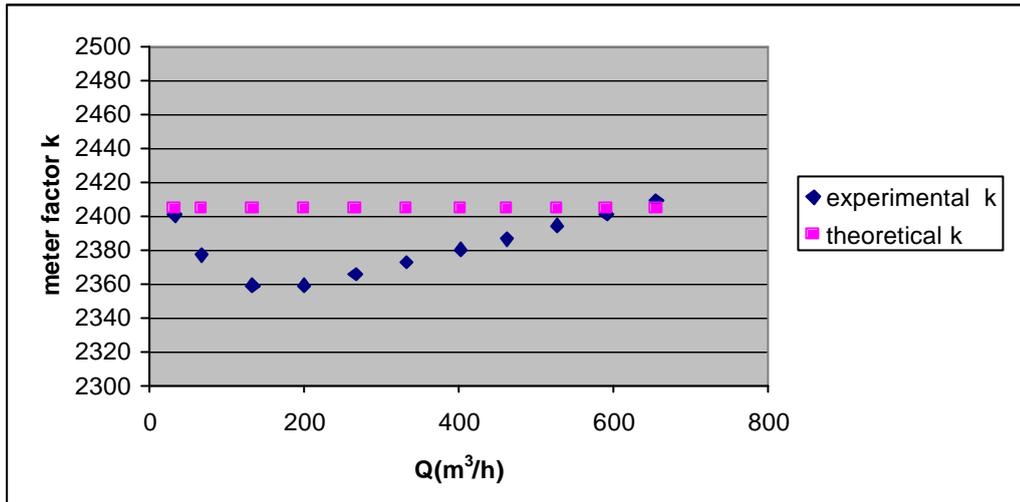
UME turbine meter is an inductive type post generation system. It produces one pulse for one complete revolution of the rotor. So the frequency can be obtained from equation (23) as;

$$f = \frac{kQ}{2p} \quad (24)$$

Results from the PTB calibration certificate [4] is used in equation (24) to calculate the meter factor “k”.

Q (m ³ /h)	Frequency (Hz)	k factor
32,944	3,498	2400,452
67,037	7,048	2376,902
132,804	13,857	2359,004
199,331	20,797	2358,768
266,103	27,844	2365,598
332,129	34,856	2372,663
401,979	42,317	2379,963
462,137	48,784	2386,557
527,159	55,824	2394,093
590,829	62,745	2400,923
654,633	69,759	2409,165

Table 1. Results from PTB calibration certificate and calculated meter factor k for each flow rate



Graph 1. Flow rate and meter factor relation

Flow rate and frequency measurement results are used in Equation (24) to calculate the meter factor k;

$$k_{\text{average}} = 2382,190$$

We divide experimental k_{average} to theoretical "k" to compare the results;

$$R = \frac{k_{\text{Experimental}}}{k_{\text{Theoretical}}} = 0,9907$$

7. Conclusions and Discussion

In this paper it is explained how mechanical movements of a turbine blade is converted to electrical signals. A Meter factor k gives the relation between the flow rate and the angular velocity of the rotor and it is calculated for UME turbine meter both as theoretical and experimental. Meter factor k can be calculated during the design process of flow meter and the design parameters such as blade angle, effective flow area in the flow meter etc. can be chosen as to give the most accurate flow rate measurement. "k" factor calculated by using the measurement results is 2382,190 , and 2404,4657 by using the design parameters of the UME flow meter.

The ratio of the experimental and theoretical results, R, is 0,9907. It seems that there are two main reasons for this difference about 1 percent. The first reason is neglected blade, bearing and viscous frictions that causes a displacement in the exit fluid velocity vector. In the ideal case, the velocity of the entering fluid displaces the blades, and the vector sum of the fluid velocity with respect to the blade and the blade rotational velocity equals the entering axial velocity vector. So ideally the velocity leaving the blades is not displaced with respect to the entering velocity. But in the real case retarding torques from blade friction, bearing friction etc. cause the exit velocity to be displaced from the entering vector, the blades therefore rotate at a speed below the theoretically predicted speed. The other factor that may change the accuracy of the results obtained is the effect of dimension tolerances of actual manufacturing process for turbine blades and rotor.

8. References

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