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Diagnostic Methods for Evaluating Performance of Turbine Flow Meter Used in Custody Transfer of Natural Gas

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ABSTRACT

Turbine flow meter is used for flow measurement of gas for custody transfer of natural gas. TFM are inferential meters that measure flow by counting the revolutions of rotor with blades, which turns in proportion to the gas velocity. When money changes hand, flow meter accuracy matters. Online Diagnostics tools if employed, can give prior alert on in-accuracy trying to creep in the system so that corrective action can be taken. Online Diagnostic tools are supplied embedded with other custody transfer meters like Ultrasonic Flow meter (USM) & Coriolis mass flow meter but not much tools are explored for the Turbine Flow meter. This paper discusses on tools/methods which can be deployed to identify any abnormality in flow measurement done by Turbine Flow meter. These tools & methods have been identified based on years of hands on working experience with turbine flow metering system used in custody transfer applications. These tools can be embedded in form of Diagnostic software and can be packaged along with supply of Turbine Flow meter to increase metering fidelity.

1. INTRODUCTION

The natural gas pipeline industry has been witnessing unprecedented changes & advancement in the recent past across the world. This is not being supplemented in direct proportion with increase in skilled workforce deployed in this industry. This mismatch thus calls for expediting the use of automation to make our equipments "smart". Term "smart" for turbine flow meter means to have self diagnosis capability to identify its healthiness & determine whether it's operating in a specified tolerance band or not. Meter should be able to provide alarms & other diagnostic data into our SCADA system so that predictive maintenance can be carried out before the problem arises.

In the subject paper, we shall be discussing the basic operating principle of turbine meter,some diagnostic methods which can help users to identify any potential mechanical or electronics problems with the turbine meter & then provide a brief glance of what a diagnostic software can look like.

2. PRINCIPLE OF OPERATION

Turbine meters are inferential measurement devices that measure a flow rate indirectly by using the natural kinetic energy of the flow as it passes through the angled blades of the turbine rotor. This causes the turbine to spin and as the blades pass by a close pre-positioned magnetic "pick up" coil. The resulting interruption of the coils magnetic field by each blade results in a pulse being produced.. The frequency of this pulse is directly proportional to the point velocity reading it is taking. From this point velocity and cross sectional area of the pipe a rough volumetric flow rate can be calculated.

Note: This is only a rough volumetric flow calculation as there are other factors that need to be considered and compensated for, before you can get an accurate volumetric flow reading.

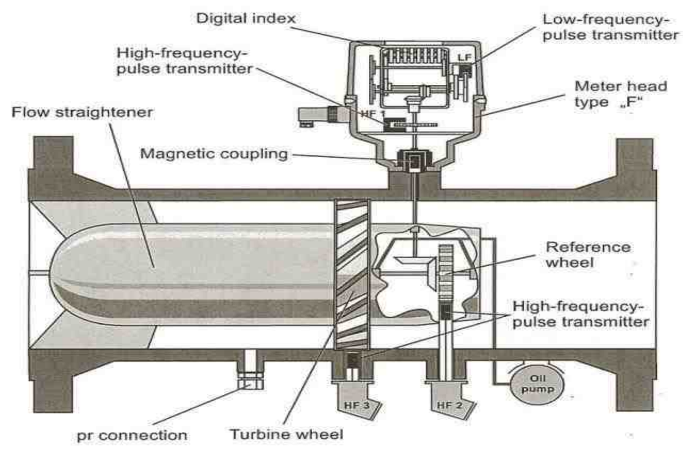


Figure 1 – Turbine Meter Layout

Equation used in Flow Measurement

Q = V X A

Q = (F X 3600) /K-Factor

Where :

Q = Volumetric Flow rate measured in m3/hr

V = Average Flow Velocity, m/s

A = Cross-sectional are of pipe, m2

K = K-Factor, Experimentally determined by the manufacturer , Pulses /m3

F = Frequency of the pulse generated by "pick –up coil" , (Pulses/s)

Correct measurement of frequency is necessary for accurate flow computation by T/M.

This F factor in the equation is only factor which is variable & varies proportional to velocity with which gas is flowing through TFM.

BLOCK DIAGRAM FOR CUSTODY TRANSFER OF NG USING TURBINE FLOW METER

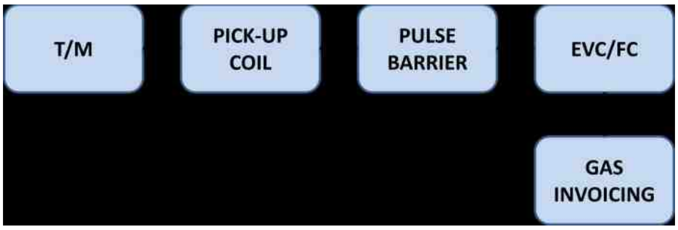


Figure 2 – Block Diagram

3. DIAGNOSTIC METHODS

One of the drawbacks of gas measurement with turbine meter technology is the fact that you have moving parts. And as we all know, moving parts eventually fail in some way .In natural gas pipeline it is not only natural gas which flows as it is accompanied by heavy hydrocarbons ,dirt ,sand etc. These contaminants damages internals of T/M like blades, bearings etc. Diagnostics are like eyes & ears of meter as they help to identify the conditions harmful to meter correct operation. Below discussed are some of the diagnostic methods which can be employed to detect the problem & take predictive action to prevent flow of un-accounted gas through the meter.

3.1. DIAGNOSTIC # 1

Comparing frequency/flow computed by other redundant installed Pick-up coils (HF-3 & HF-2) installed over T/M

Manufacturer provide various pick-up coil/ pulser installed over T/M ,they include HF-3 pulser installed over rotor blade ,HF-2 pulser installed over reference wheel attached to shaft of the main rotor ,HF-1 & LF installed over index head/mechanical counter.

Generally HF-3 is used for flow computation as its most accurate of all. EVC/FC have the facility to compute Blade ratio which is ratio of frequency generated by HF-3 & HF -2 pulser ,this ratio need to be 1 for correct flow computed using HF-3 pulser. K-factor for both HF-3 & HF-2 pulser is approximately same.

If suppose one of the blade of rotor has got damaged but reference wheel is intact then frequency output by HF-3 will be less than the frequency output of HF-2 pulser. Blade ratio will be less than 1.

Figure: 3 shows the hourly average of frequency computed by HF-3 & HF-2 pulser from 4 am to 8 am , it can be observed that meter was computing flow correctly for period 4 to 6 am but after 6 am some discrepancy has occurred in rotor balde or HF-3 pulser as its output has reduced & blade ratio has become less than 1.

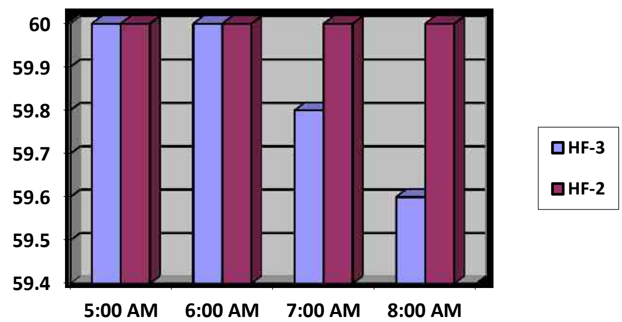


Figure 3 – HF3 & HF3 Healthiness

3.2. DIAGNOSTIC # 2

Ensuring Frequency Output, F generated by "Pick-up Coil" to lie between f min & f max of Pulse Barrier selected in accordance to F min & F max for Q min & Q max for the T/M.

F max for Pulser = (Q (max) X K-factor)/3600

F min for Pulser = (Q (min) X K-factor)/3600

F should lie between f (min) & f (max) for correct flow measurement by the turbine meter where f max > F max & f min < F min.

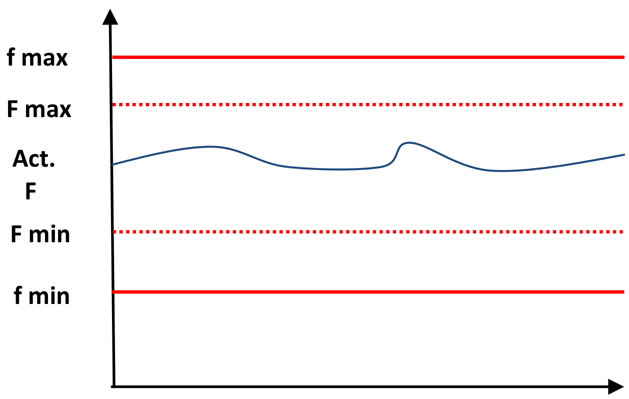


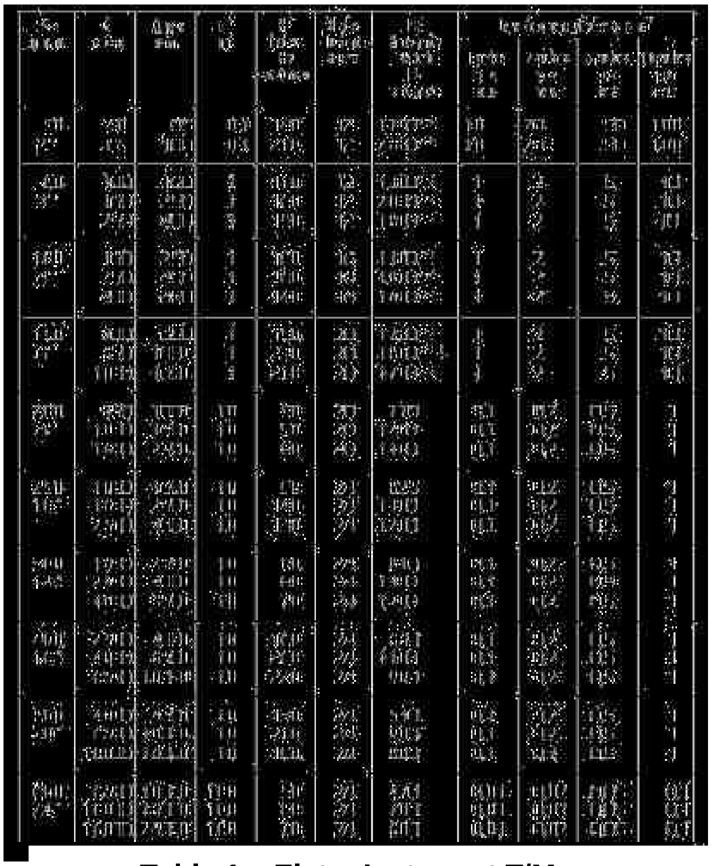
Figure 4 – f min ≤ F ≤ f max

If turbine meter is over-speeding then F may exceed f (max) & if there is some obstruction to flow path in turbine rotor i.e. then F may be less than f (min) & flow measured will be less than actual flow.

Frequency generated by T/M pick-up coil is transmitted to EVC/Flow Computer using a Pulse Barrier. At some of the sites it has been found that frequency maximum f max for barrier is less than the F max for T/M , in this case when T/M is operating at Q max then frequency output F will get clipped to frequency maximum specified for that barrier installed & flow read by EVC/Flow Computer will be less than actual flow. It is necessary to ensure that installed barrier must cover the entire flow range of T/M i.e. Q(min) to Q(max).

CASE STUDY

For Elster instromet make T/M , values for F (max) & F (Min) recommended by the vendor are show below in the table.



. **Table 1 – Elster Instromet T/M**

Illustration:
For 4" G-160 Turbine meter installed at some site

Q (max)	= 250 m3/hr
Delivery Pressure	= 20 kg/cm2
Q (max) at standard base conditions	= 5,000 SCMH
K-Factor	= 15840 Pulses/m3
F (max) corresponding to Q (max)	= 1100 Hz

Now the Pulse Barrier installed has rated max frequency 1000 Hz. Hence it will read frequency 1000 Hz when actual frequency transmitted by the pick-up coil is 1100 Hz.

Q (read by EVC/FC)	= (F X 3600)/K-Factor = (1000X3600) /15840 = 227 m3/hr
Q at standard base conditions	= 4,540 SCMH
Error	= -9.2 %

This means EVC/FC will read flow 9.2% less than actual flow if we have just installed a pulse barrier of rated frequency 100 Hz less than the F (max) required corresponding to Q (max).

Un-accounted gas given to consumer = 460 SCMH

Loss in Rs considering average prevailing price of gas in India Rs 10/SCM will be Rs 4600 /hour , Rs 110,400 /day ,Rs 4 crores /year.

3.3. DIAGNOSTIC # 3

Comparing Waveform of Frequency generated by Pick-up coil to a standard waveform for selected T/M.

Frequency waveform generated by Pick Up Coil shall be analyzed & compared first with standard waveform for selected T/M running with permissible uncertainty in measurement. .If it fails the comparison test then this waveform shall be analyzed using latest data analytical tools to compare it with various waveforms patterns stored in a database for different type of scenarios like damaged rotor blade ,dirt accumulation ,magnetized rotor ,loose bearings etc. .This will help us to diagnose the problem in its early stages.

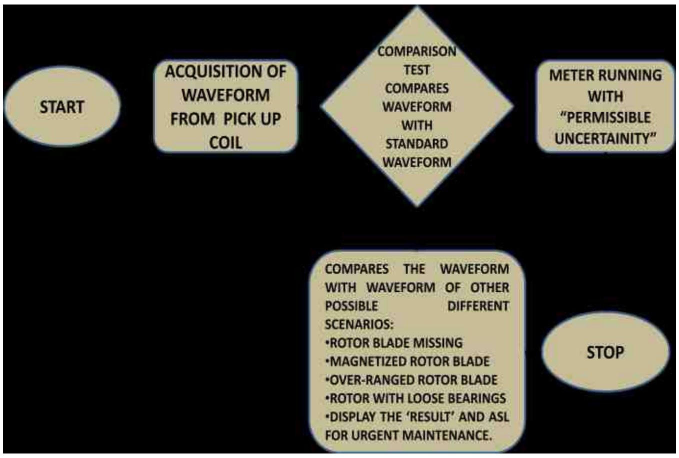


Figure 5 - Algorithm for analyzing the waveform

3.3.1. SCENARIO: Normal Rotor

Figure 6 shows waveform of signal from pick-up coil of a healthy rotor

Figure 7 shows waveform of signal frequency from pick-up coil of a healthy rotor

Rotor waveform can be depicted as a pure sinusoidal waveform

Y = A Sinwt

w = 2πFt

F = Rotor frequency in Hz

<u>For 4" G-160 Turbine meter installed at some site</u>

Q (max)	= 250 m3/hr
Delivery Pressure	= 20 kg/cm2
K-Factor	=15840 Pulses/m3
F (max) corresponding to Q (max)	= 1100 Hz

For Frequency say F = 880 Hz

Q (Uncorrected flow read by EVC/FC)	= (F X 3600)/K-Factor
Q	= 200 m3/hr
Q at Standard base conditions	= Uncorrected flow x Delivery Pressure = 4000 SCMH

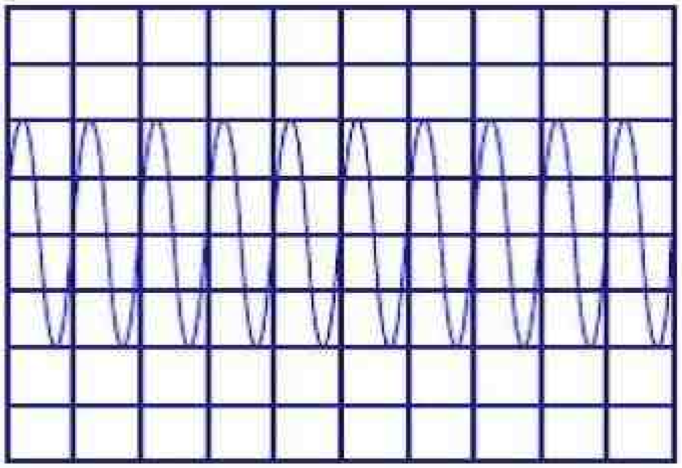


Figure 6 - Waveform of signal from pick-up coil of a healthy rotor

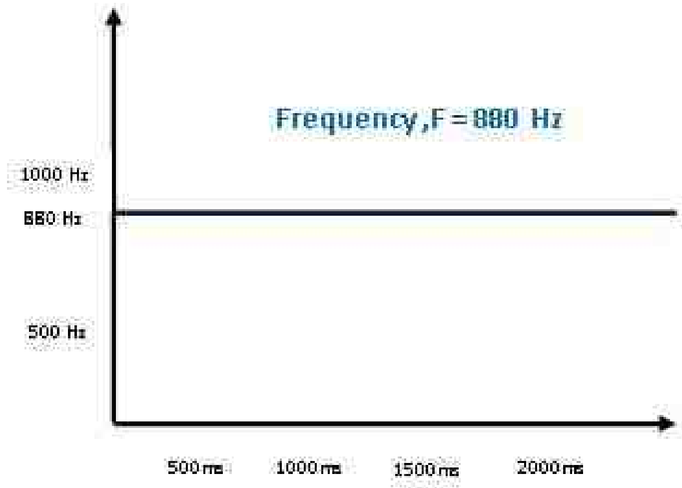


Figure 7 - Waveform of signal frequency from pick-up coil of a healthy rotor

3.3.2. SCENARIO : Missing Rotor Blade

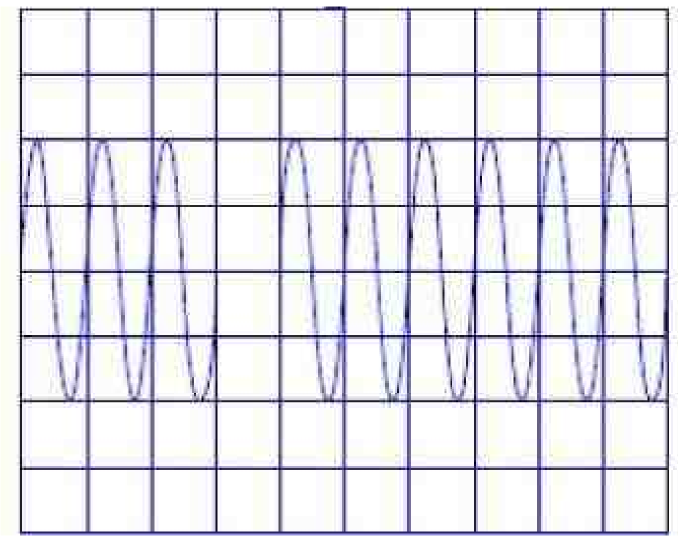


Figure 8 - Waveform of signal from pick-up coil of rotor having missing blade

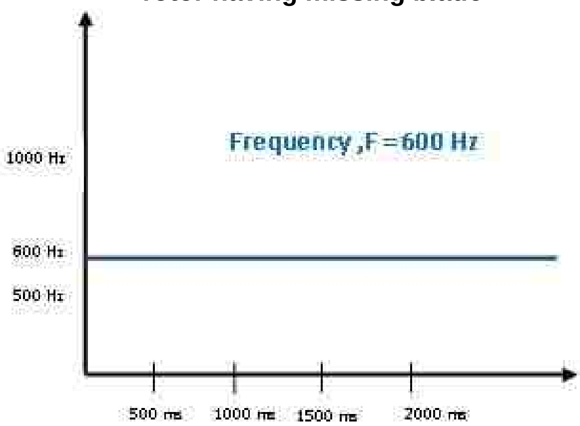


Figure 9 - Waveform of signal frequency from pick-up coil of rotor having missing blade

<u>For 4" G-160 Turbine meter installed at some site</u>

Q (max)	= 250 m3/hr
Delivery Pressure	= 20 kg/cm2
K-Factor	=15840Pulses/m3
F (max) corresponding to Q (max)	= 1100 Hz

Due missing blade , frequency shall get reduced let suppose F = 600 Hz

Q (Uncorrected Flow read by Flow Computer)	= (F X 3600)/K-Factor
Q	= 137 m3/hr
Q at Standard base conditions	= Uncorrected flow X Delivery Pressure = 2740 SCMH
% Error due to Missing Blade	**= -31.5 %**

3.3.3. SCENARIO : Bent Blades

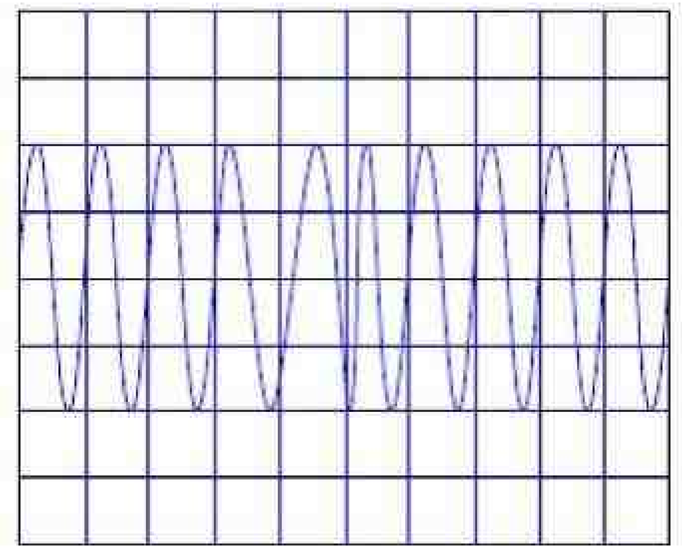


Figure 10- Waveform of signal from pick-up coil of rotor having bent blades

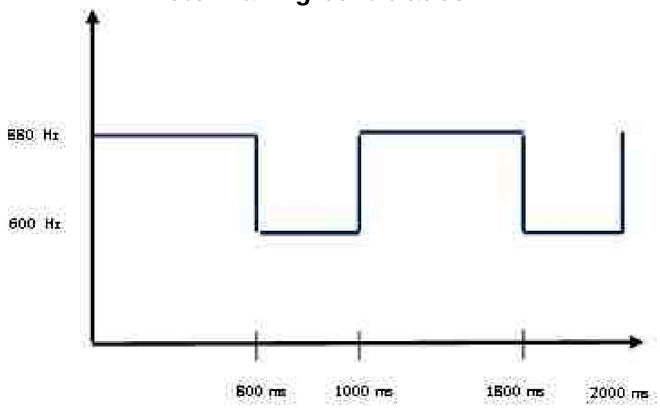


Figure 11 - Waveform of signal frequency from pick-up coil of rotor having bent blades

<u>For 4" G-160 Turbine meter installed at some site</u>

Q (max)	= 250 m3/hr
Delivery Pressure	= 20 kg/cm2
K-Factor	=15840Pulses/m3
F (max) corresponding to Q (max)	= 1100 Hz

Due to bent blades, frequency will vary say suppose 880 Hz for first 800 ms & then 600 Hz for next 200 ms .This cycle then repeat itself.

Frequency , F shall be	= $1/T * \int F\,dt$ where T is 1000 mS. = 824 Hz
Q (Uncorrected Flow read by FC)	= 187 m3/hr
Q at Standard base conditions	= 3745 SCMH
% Error due to Missing Blade	**= -6.4 %**

3.3.4. SCENARIO: Bent Blades

Figure 12 shows waveform of signal from pick-up coil of magnetized rotor due to interference from external sources.

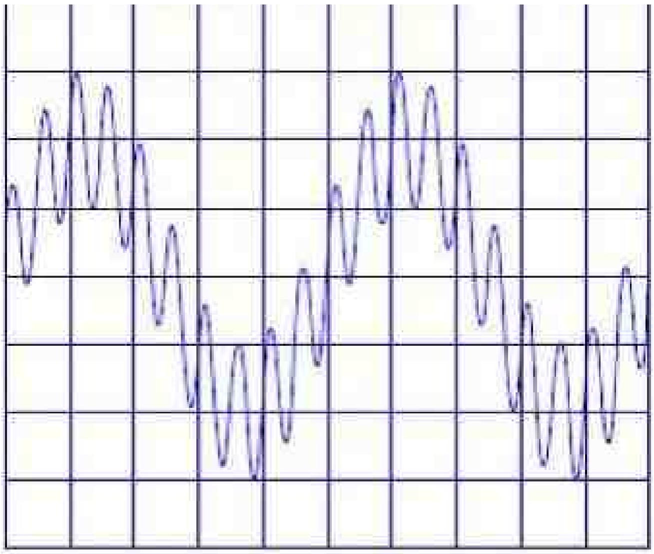


Figure 12 – Waveform of signal from pick-up coil of magnetized rotor

3.3.5. SCENARIO : Over-Ranged Rotor Blades

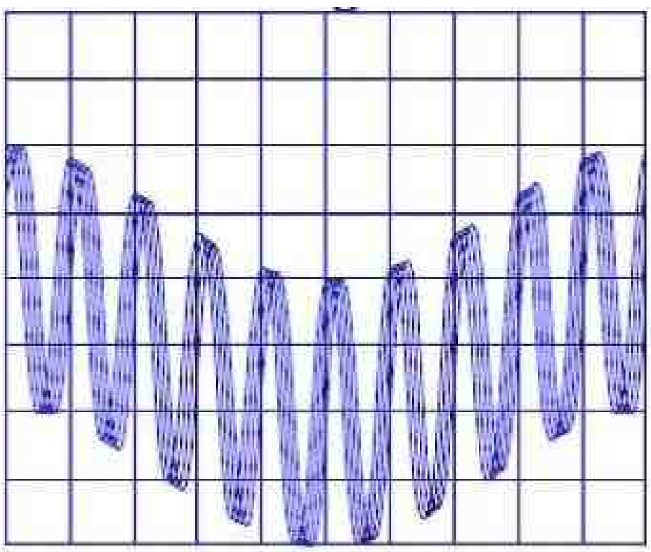


Figure 13 – Waveform of signal from pick-up coil of rotor operating above its range

3.3.6. SCENARIO: Rotor with Loose Bearings.

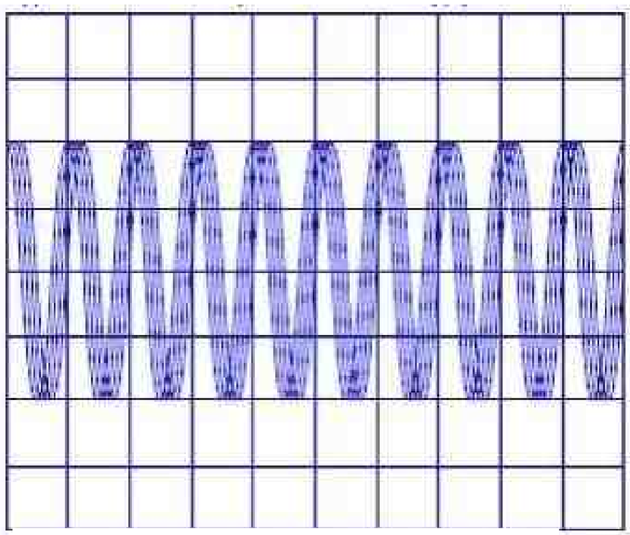


Figure 14 – Waveform of signal from pick-up coil of rotor with loose

All these waveforms discussed above represent some of the many scenarios which can be observed during operation of Turbine flow meter.

As frequency is the parameter on which flow computed is directly proportional ,therefore these waveforms can be analyzed either using portable digital oscilloscope or vendor can provide software that can run on PC/laptop where all these waveforms can viewed /logged & can be analyzed for taking suitable action before problem get aggravated & it affects metering.

3.4. DIAGNOSTIC # 4

Mechanical Counter Readings Vs FC Un-Corrected Reading

There is a mechanical counter/index head coupled to the rotor of T/M using some mechanical arrangement. Counter register actual volume in m3 passed through T/M.

Volume of gas in m3 passed through T/M for any period of time can be compared with the volume read by the EVC/FC , if there is any mismatch more than permissible value then it indicates there is some problem with either EVC/FC ,Pick-up coil or may be with mechanical counter.

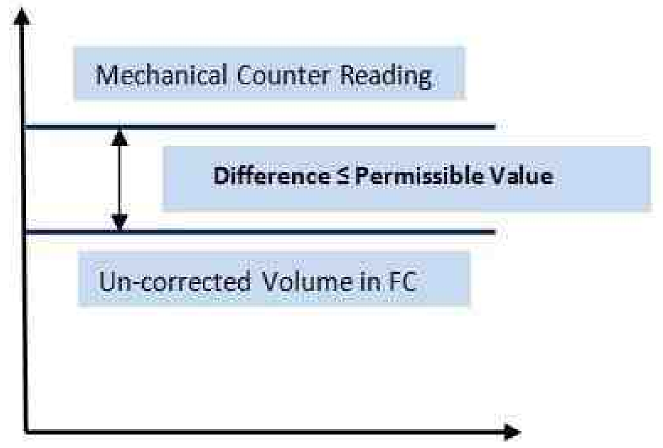


Figure 15 – Mechanical Counter Readings Vs FC Un-Corrected Reading

3.5. DIAGNOSTIC # 5

Resistance of Pick Up Coil Vs Manufactured Specified Value

Resistance of Pick Up Coil should lie near to manufactured specified value for accurate metering. If there is some problem with the pick - up coil then its resistance will differ with the manufactured specified value , which may be the reason for change in calculated flow .

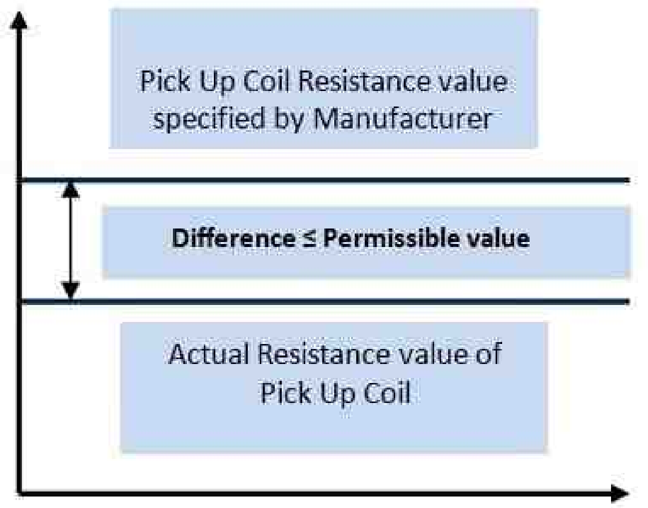


Figure 16 – Resistance of Pick Up Coil Vs Manufactured Specified Value

4. DIAGNOSTIC SOFTWARE

All the diagnostic methods discussed above can be incorporated in a diagnostic software supplied by vendor along with supply of T/M. This will help the operator to view the diagnostics dynamically on the computer screen & even with basic acumen of turbine metering he can take predictive action depending upon the pre-alarms generated by the software.

Below table no 2 summarise list of diagnostic methods discusses above.

Table No 2 – Summary of Diagnostic Methods

Diagnostic #	Description
1.	**Comparing frequency/flow computed by other redundant installed Pick-up coils (HF-3 & HF-2) installed over T/M**
2.	**Ensuring Frequency Output, F generated by "Pick-up Coil" to lie between f min & f max of Pulse Barrier selected in accordance to F min & F max for Q min & Q max for the T/M.**
3.	**Comparing Waveform of Frequency generated by Pick-up coil to a standard waveform for selected T/M.**
4.	**Mechanical Counter Readings Vs FC Un-Corrected Reading**
5.	**Resistance of Pick Up Coil Vs Manufactured Specified Value**

Basic layout of software page is shown in below figure no 17 :

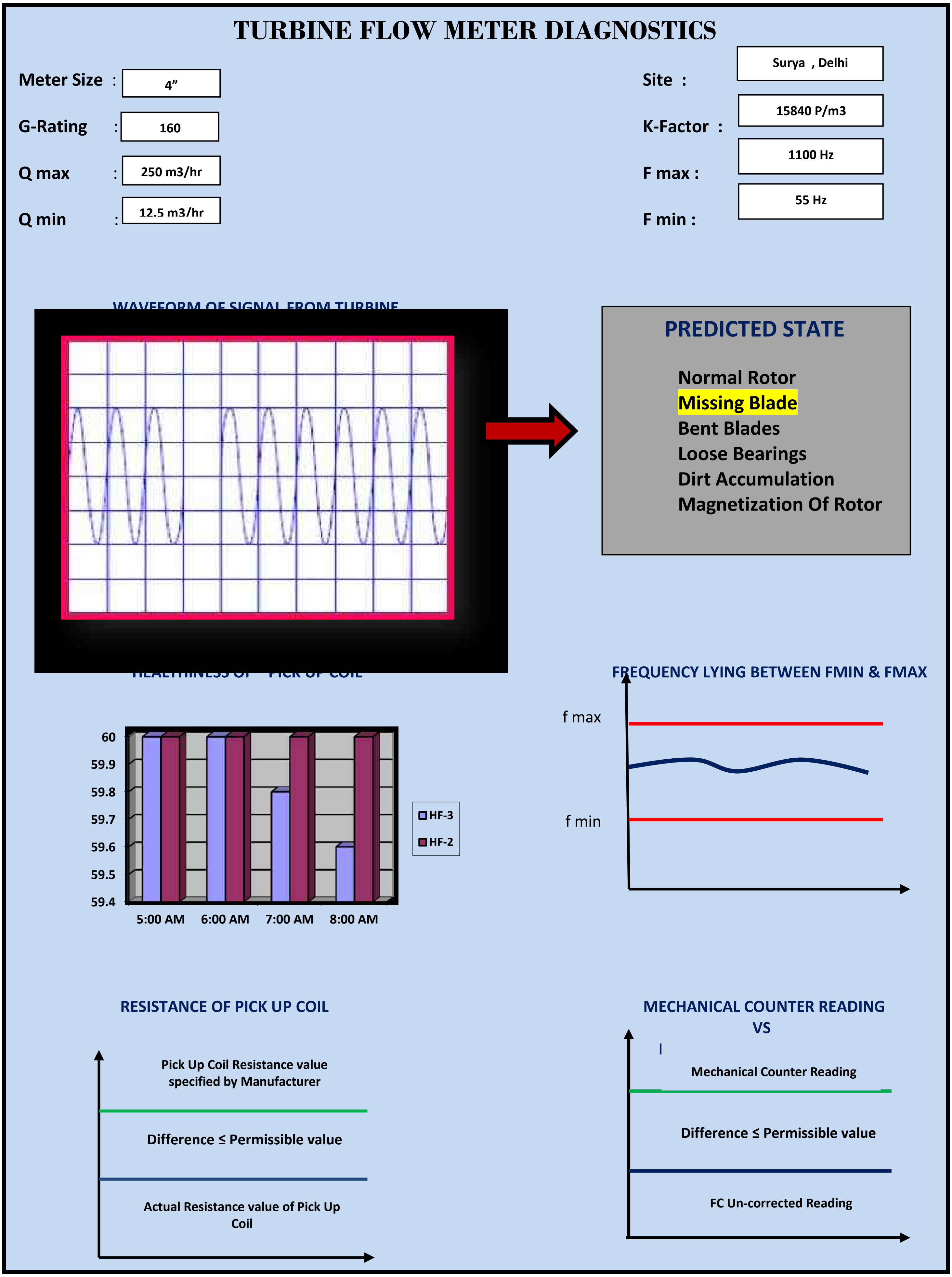


Figure 17 – Software Page

5. CONCLUSION

TFM is very accurate method of measuring gas flow rate provided proper maintenance activity is carried out & various states of art technological/diagnostic tools/ are utilized for carrying out predictive maintenance of TFM instead of the breakdown maintenance. Methods discussed above can be used to diagnose the problem just at start of its occurrence & can help us reduce percentage of uncertainty in gas flow measurement. **Diagnostic software can be provided along with supply of T/M which shall consist of a database which comprises of Pick-up Coil waveforms for all kinds of problems which may creep into the T/M . Software can utilise the tremendous capabilities of latest data analytics tools like Big Data to analyse the dynamic waveform data taken from T/M in operation & subsequently alerting the user by popping up a message/alarm which shall in turn display the state of meter.**

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Significant Achievements	:	• Managed CRM, Operation & Maintenance activities involved in 12 Customer Gas Dispatch T/L's in NCR Region as an Terminal In-Charge. • Designed, procured, installed & commissioned more than 30 Natural Gas Metering skids (USM/TFM/Orifice). • Designed, procured, installed & commissioned up-graded PLC in HDPE Extruder Control System at GAIL Petrochemical Plant at Pata . • Achieved Seamless Fortnightly Gas Invoicing of 15 consumers in NCR region through Gas Management Systems (GMS) implemented in SAP as per terms & conditions defined in GSA & GTA's. • Successfully Implemented IMS (ISO 9001, ISO 14001, and OHSAS 18001) in maintenance base in NCR Region as a Team Member and audited other maintenance base to ensure compliance. • Participated as a active team member in several Natural Gas Grid pipeline expansion & modification projects in Haryana, Uttar Pradesh, Punjab, Rajasthan & played a major role in setting up of gas supply installation bases at consumer's end.
Number of Papers Published in Journals	:	NIL
Number of Papers Published in Conferences	:	NIL