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CORRECTION FOR K FACTOR OF GAS TURBINE FLOW METER

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ABSTRACT

According to the International Standard ISO 9951 all gas turbine flow meters should have a maximum permissible relative error of ± 1% over the higher flow range (from $0.2Q_{max}$ to Q_{max}), in the lower flow range (Q_{min} to $0.2Q_{max}$) the maximum permissible relative error is ± 2%. Usually the linearity of k factors, in percent, is used to express the basic relative error of a gas turbine meter. That means in the higher flow range the gas turbine meters shall have maximum permissible linearity of ± 1%, and in the lower flow range the gas turbine meters shall have maximum permissible linearity of ± 2%. The method commonly used to determine the mean k factor, K_0 , is: At first, the values of K_{max} and K_{min} are found out in the higher flow range, and then the mean K factor, K_0 , is calculated. Finally, the maximum deviation of K factors from K_0 in the higher and lower flow ranges are evaluated to make an error judgment. In some cases this method might introduce a bias error into the K_0, because the shapes of K factor signature curves (the different modes of K factors distribution in different flow range) were not considered. Therefore, it is necessary to make different corrections for K_0 in different cases. Our approaches are as follows: When K_{min} appears in the lower flow range and the K_{max} appears in the higher flow range, $K_0= (A K_{max} + K_{min})/2$, here A=1.0099; When the K_{max} appears in the lower flow range and the K_{min} appears in the higher flow range, $K_0= (B K_{max} + K_{min})/2$,here B=0.9902; When both the K_{max} and the K_{min} appear simultaneously in the same lower or higher flow range,
$K_0 =(C K_{max} + K_{min})/2$, here C=1.0. During the individual calibration of each turbine meter this method has shown clear positive effects. While consideration was given to meter's performance in the higher flow range, the performance of turbine meter in the lower flow range has been improved, therefore, more gas turbine meters are ensured to be up to standard. Based on the European Standard PrEN12261:1998 Turbine Gas Meter, the WME (Weighted Mean Errors) were calculated. The WME show that this is an easy method to obtain the proper value of mean K factor for gas turbine meter.

INTRODUCTION

Gas turbine meters are widely used in Gas industry. The turbine meter belongs to pulse-frequency type flow meter. The K factor defines the relationship between flow rate and frequency for turbine flow meters. The K factor is defined as $K= f/Q$ = Pulse/unit volume ....(1)

Where, Q denotes the volume flow rate (in cubic meter per second) and f is frequency in pulses per second. For gas turbine mete rs, the K factor is obtained over a flow rate range and plotted versus flow rate. A typical signature curve for a gas turbine meter is shown in Fig. #1

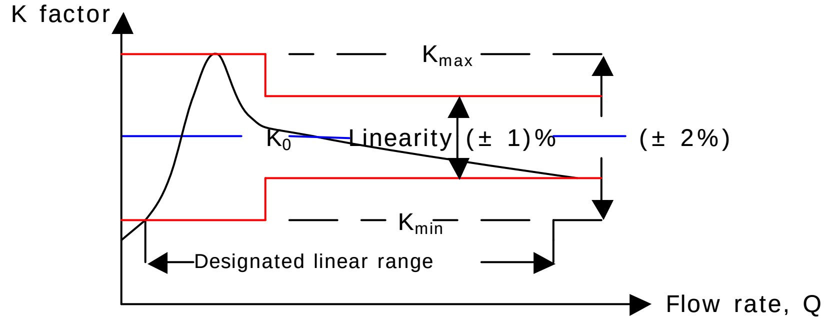

Fig. #1 K factor signature curve

Usually, the linearity of K factors, in percent, is used to express the basic relative error of a gas turbine meter. The linearity of a gas turbine meter is the maximum percentage deviation of its true K factor from the mean K factor across the linear range. The mean K factor, K_0 , is defined as the average of the maximum and minimum K factors over the designated flow range. $K_0 = (K_{max} + K_{min})/2$ ....(2)
The linear range of a gas turbine meter is that flow range over which the output frequency is proportional to flow rate within the limits specified by the ISO Standard (or by manufacturer). Gas turbine meters may be applied over more than one range (within the minimum and maximum ratings by the ISO standard/ the manufacturer). Each range may have a different linearity.
According to the International Standard ISO 9951 all gas turbine meters should have a maximum permissible relative error of ± 1% over the higher flow range ($0.2Q_{max}$ to Q_{max}); in the lower flow range (Q_{min} to $0.2Q_{max}$) the maximum permissible error is ±2%. From the statements mentioned above it is obvious that in the higher flow range the gas turbine meters shall have maximum permissible linearity of ±1%; and in the lower flow range the gas turbine meters shall have maximum permissible linearity of ±2%.
So far the method commonly used to determine the mean K factor is as follow:

1. The values of K_{max} and K_{min} are found out in the higher flow range;
2. Using the equation (2), the K_0 is calculated;
3. The maximum deviation of K factors from K_0 in the higher and the lower flow ranges are evaluated to make an error judgment.

In some cases this method might introduce a bias error into K_0, because the shapes of the signature curves (the different modes of K factors distribution in different flow ranges) were not considered. Therefore, it is necessary to make a different correction for K_0 in different case.

THE CORRECTION FOR K FACTOR

According to the International Standard ISO 9951 an individual calibration of each meter should be made. The calibration data provided shall include the K factors at Q_{min}; 0.1;0.25;0.4;0.7 of Q_{max} and $Q_{max.}$ However, the problem is that K_{max} and K_{min} might appear in different flow range. In different case different approach should be taken to solve this problem. The discussions on different cases are as follows:

CASE #1:

The K_{min} appears in the lower flow range, but the K_{max} appears in the higher flow range, as shown in Fig.#2 :

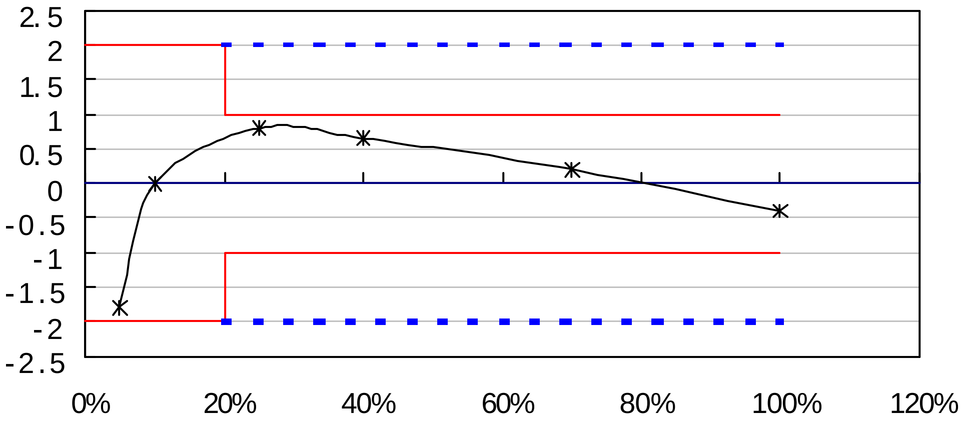

Fig.#2

On the basis of the requirements of the International Standard ISO 9951 it is essential to have following relationships: $\frac{K_{max} - K_O}{K_O} \times 100\% \leq 1.0\%$ …(3) ,as the K_{max} appears in the higher flow range;

and $\frac{K_O - K_{min}}{K_O} \times 100\% \leq 2.0\%$ …(4), as the K_{min} appears in the lower flow range. As the equations (3) and (4) are simultaneous equations, from equation (3) the following equation is derived:

$$\frac{K_{max} - K_O}{K_O} + 1 \leq 1 + 1.0\%$$

therefore,

$$\frac{K_{max}}{K_O} \leq 1 + 1.0\% \quad \text{….(5)}$$

from equation (4) the following equation is obtained:

$$\frac{K_O - K_{min}}{K_O} + 1 \leq 1 + 2.0\%$$

therefore,

$$\frac{2K_O - K_{min}}{K_O} \leq 1 + 2.0\% \quad \text{…..(6)}$$

Taking the extreme value for equation (5) and equation (6) separately, and then the equation (5) is divided by equation (6) the following result is derived:

$$\frac{K_{max}}{2K_O - K_{min}} = \frac{1 + 1.0\%}{1 + 2.0\%} = \frac{1}{A} \quad \text{……….(7)}$$

Instead, the equation (7) can be rearranged into a functional equation as

$$K_O = \frac{AK_{max} + K_{min}}{2} \quad \text{……..(8)}$$

Where: A=1.0099

The limitation for using equation (8) in case #1 is to meet the following inequality:

$$\frac{1}{A} K_{max} > K_{min} \quad \text{…(9)}$$

The calibration data of 8 gas turbine meters, whose diameters are 100 mm, are shown in the top part of the table #1.

The results of the data processing by commonly used method are shown in the middle part of the table #1.

The results of the data processing by the correction method, reported in this paper, are shown in the lower part of the table #1, where d_H (%)is the linearity in the higher flow range;

d_L (%) is the linearity in the lower flow range.

From table #1 it is clear that if the commonly used method is used, then the linearity in the lower flow range would exceed the limit. That means: According to the requirements of ISO 9951 these 8 turbine meters are not acceptable. However, if the correction method is used, then all parameters, including d_H, d_L and WME(%), are acceptable.

Table #1

Flow Points	K FACTORS							
	Meter#1	Meter#2	Meter#3	Meter#4	Meter#5	Meter#6	Meter#7	Meter#8
100%	3234.3	3292.7	3326.6	3261.6	3237.0	3279.0	3269.3	3295.0
70%	3220.1	3289.0	3297.0	3238.0	3235.0	3286.9	3260.5	3270.1
40%	3219.4	3286.1	3284.1	3230.5	3233.0	3284.1	3256.2	3266.6
25%	3218.8	3282.4	3277.8	3247.2	3238.2	3283.5	3257.9	3262.3
10%	3225.9	3284.1	3277.1	3247.6	3233.4	3280.0	3259.9	3268.0
5%	3157.1	3219.7	3233.8	3172.3	3170.9	3216.9	3196.1	3211.3
K_O	3227	3288	3302	3246	3236	3283	3263	3279
d_H (%)	0.25	0.17	0.74	0.48	0.07	0.12	0.21	0.51
d_L (%)	-2.1	-2.1	-2.1	-2.3	-2.0	-2.0	-2.1	-2.1
The initial calibration data and the results, processed by commonly used method, are shown above; The results, processed by using equation (8), are shown below								
K_O	3211	3272	3297	3233	3220	3268	3249	3269
d_H(%)	0.73	0.63	0.89	0.88	0.53	0.59	0.62	0.80
d_L (%)	-1.68	-1.60	-1.92	-1.88	-1.52	-1.56	-1.63	-1.76
WME (%)	0.20	0.43	0.03	0.26	0.42	0.47	0.32	0.09

It is obvious, that because of using of this correction method the percentage of the qualified turbine meters would be increased, as shown in Fig.#3

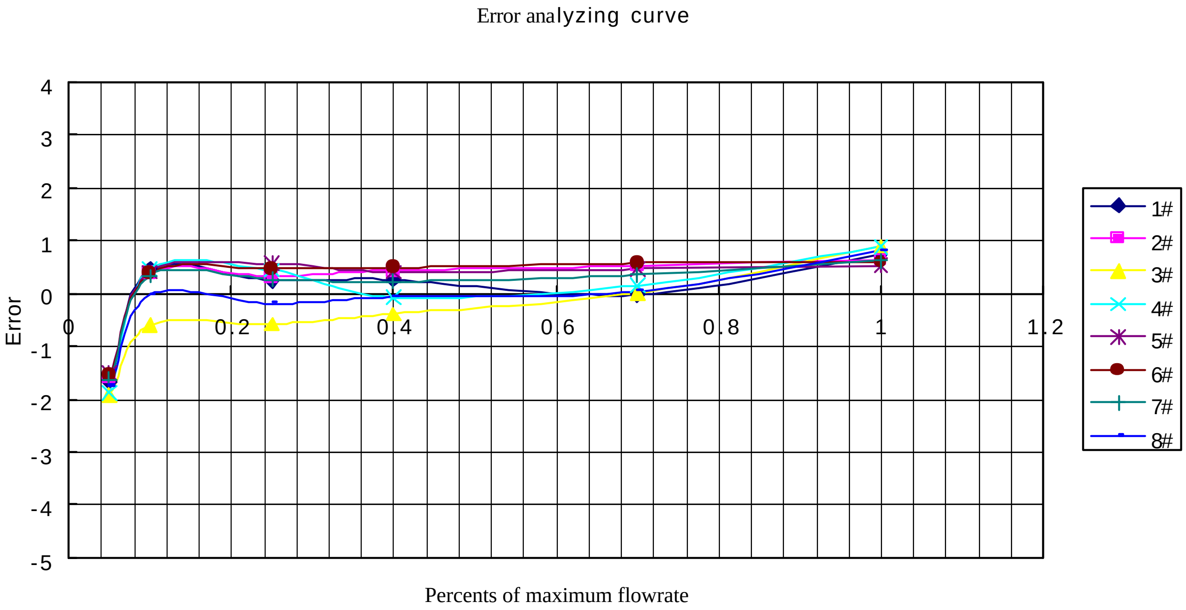

Fig.#3

CASE #2

The K_{max} appears in the lower flow range (Q_{min} to $0.2Q_{max}$) and the K_{min} appears in the higher flow range ($0.2Q_{max}$ to Q_{max}), as shown in Fig. #4

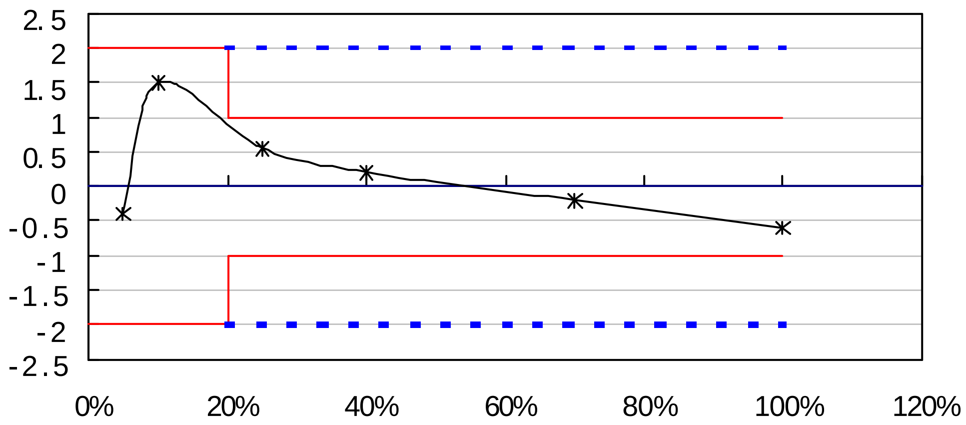

Fig.#4

The equation for correcting K_0 is derived by the same way as in case #1. As the theoretical proving and the mathematical derivation in case #2 are similar to that one in the case #1, therefore, the process of mathematical derivation is neglected here. The equation for correcting K_0 in case #2 is as follow:

$$K_O = \frac{BK_{max} + K_{min}}{2} \quad \ldots\ldots\ldots(10)$$

Where: B=0.9902

The limitation of using equation (10) is the following inequality: $BK_{max} > K_{min}$ .... (11)

The initial calibration data of 8 turbine meters, whose diameters are 100mm, for the case #2; the results processed by the commonly used method; and the results processed by this correction method are shown in the Table #2.

Table #2

Flow Points	K FACTORS							
	Meter#1	Meter#2	Meter#3	Meter#4	Meter#5	Meter#6	Meter#7	Meter#8
100%	3202.9	3246.2	3222.1	3212.8	3257.7	3261.0	3221.6	3196.8
70%	3206.5	3245.3	3218.5	3220.5	3260.8	3270.9	3208.9	3201.5
40%	3209.3	3246.5	3220.6	3224.7	3264.0	3270.5	3217.5	3203.3
25%	3210.5	3247.1	3223.4	3230.9	3259.5	3270.1	3224.1	3206.5
10%	3266.0	3310.2	3282.9	3282.2	3324.6	3324.4	3279.9	3267.6
5%	3213.9	3261.8	3224.8	3239.8	3258.2	3284.2	3223.0	3219.2
K_O	3207	3246	3221	3222	3261	3266	3217	3202
d_H(%)	0.13	0.03	0.08	0.29	0.10	0.15	0.25	0.16
d_L(%)	+1.84	+1.98	+1.92	+1.87	+1.95	+1.79	+1.96	+2.05
Below: Results, by using equation (10) ; Above: Calibration data & results, by commonly used method								
K_O	3218	3262	3234	3231	3275	3276	3228	3216
d_H(%)	0.47	0.48	0.48	0.56	0.53	0.46	0.59	0.59
d_L(%)	+1.49	+1.48	+1.51	1.58	+1.51	+1.48	+1.61	+1.60
WME (%)	-0.24	0.37	-0.31	-0.19	-0.34	-0.13	-0.26	-0.32

The results after correction for K_0 by equation (10) are also shown in Fig. #5

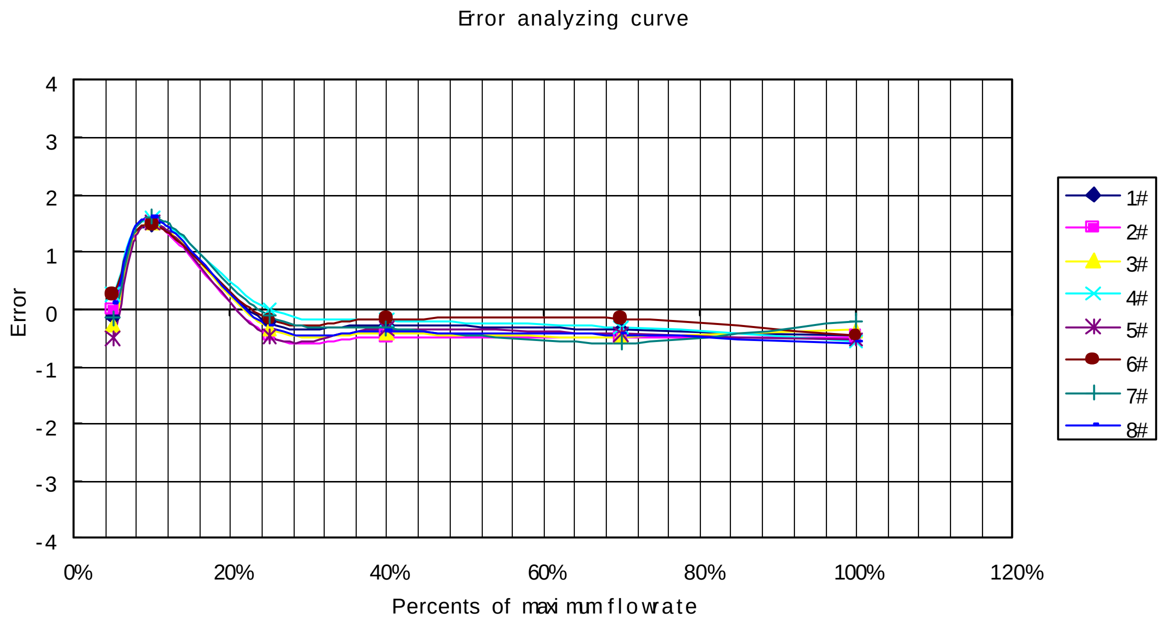

Fig. #5

CASE #3

The K_{max} and the K_{min} appear simultaneously in the lower flow range (Q_{min} to $0.2Q_{max}$) or in the higher flow range ($0.2Q_{max}$ to Q_{max}), as shown in Fig. #6 and Fig. #7

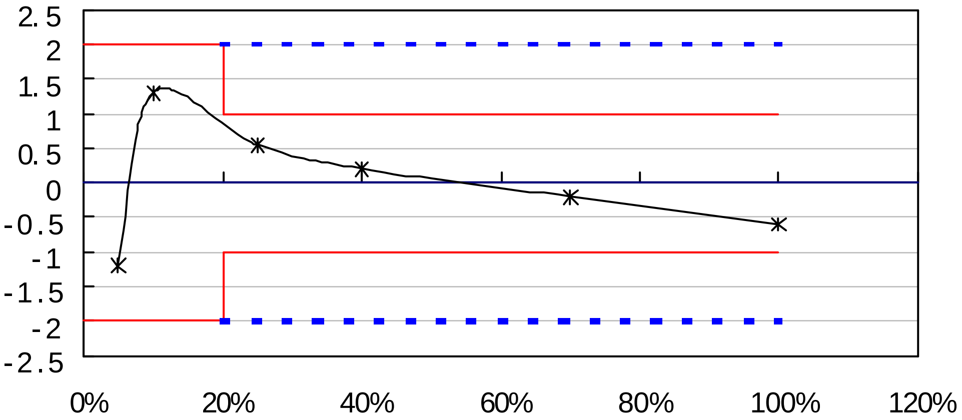

Fig. #6

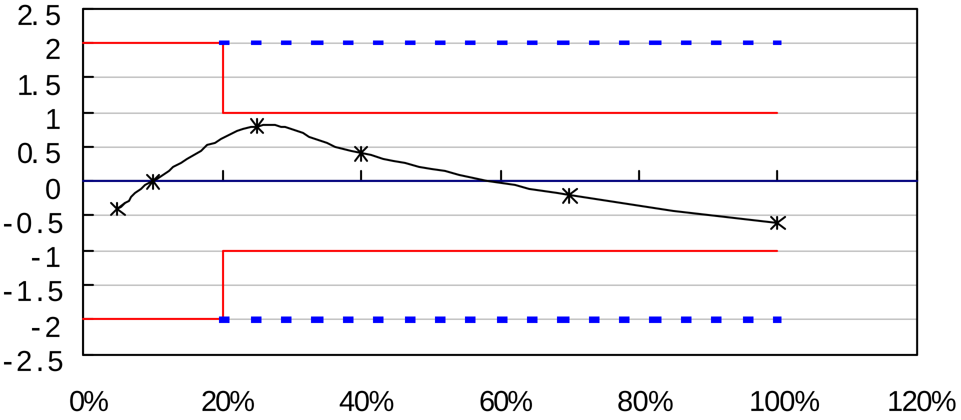

Fig. #7 K_{max} and K_{min}?($0.2Q_{max}$~ Q_{max})

In case #3, it has no need of introducing correcting factor into the mean K factor equation. Or the correcting factor is equal to 1.

$$K_O = \frac{CK_{max} + K_{min}}{2} \qquad \text{..................(12)}$$

Where: C=1.0

<u>CONCLUSION</u>

1. As the International Standard ISO 9951 requires different linearity in different flow range. The necessity of introducing different correcting factor (A or B) into the mean K factor equation is theoretically proved.

2. Based on the error analysis and comparison the necessity, the versatility and the applicability of this correction method have been practically verified.

3. This correction method has shown positive effects: While considerations are given to the meter's performance in the higher flow range, the meter's performance in the lower flow range has been improved.

4.Because of using of this correction method the percentage of the qualified turbine meters is increased. More gas turbine meters are ensured to be up to standard.

5.Based on the European Standard PrEN12261:1998E Turbine Gas Meter, the WME (Weighted Mean Errors) were calculated. The WME show that this is an easy method to obtain the proper value of mean K factor for gas turbine meter.

6.This correction method is suitable for gas turbine meters working with EVC (Electronic Volume Correctors) and the gas turbine meters of general purpose.

REFERENCE

[1] INTERNATIONAL STANDARD **ISO 9951,** First edition 1993.12.01, Measurement of gas flow in closed conduits---Turbine meters

[2] European Standard PrEN12261:1998E Turbine gas meter(English version)

[3] AGA Report #7, Measurement of fuel gas by turbine meters

[4] Flow Measurement Engineering Handbook, written by Mr. R. W. Miller, Third edition,1993