Error Analysis of Trial Data on the Pump Trial Stage

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Abstract: After the pump trial stage is finished, the hydraulic performance data of the trial pump can be obtained on the pump trial stage, including flow rate, head and efficiency etc. But it is difficult to judge accuracy of the trial data. A method of error analysis is put forward in this paper, in order to solve this problem. Firstly the theoretical range of performance data error is analyzed and then observe whether the data fluctuation on trial is within the expected theoretical range of error. This is the basis of determining whether the trial data is accurate. In this way, it is easy to judge accuracy of the trial data and the ability of obtaining trial data accurately on the pump trial stage is proved. All this meets expected demand.

1. Introduction

After the pump trial stage is finished, the hydraulic performance data of the trial pump can be obtained on the pump trial stage, including flow rate, head and efficiency etc. The measure accuracy of the data is of great significance to evaluate the performance of trial pump, especially to improve the performance of the pump. Meanwhile the accuracy of the data also reflects the ability of obtaining accurately the data on the pump trial stage.

But it is difficult to judge the accuracy of the data, because there is no standard flow and head pump to calibrate the pump trial stage. It is also difficult to set up check device such as weighing device and load device.

But there are always ways. Data measure basis on the pump trial stage is that all instruments are verified by the relevant verification units and the corresponding verification certificates are granted. This means that special check device such as weighing device, load device no longer be needed for accurate measure of trial data on the pump trial stage. What only need to do is that the verification certificates are applied correctly to the control system.

All instruments are verified accurately. The measure method and the analysis method are also verified strictly. So during the analysis of trial data, if the trial data shows good precision (one characteristic of accuracy, fluctuation range of trial data is small), the trial data is also considered with good veracity (the other characteristic of accuracy, the difference between the measured value and the true value is small). This means that the accuracy is high.

2. The basic concept of error and error transfer

2.1 The concept of error

2.1.1 Basic errors. The basic errors include absolute error, relative error and quoted error. The meanings of these three basic errors are as follow:

Absolute error: the difference between the measured value and the true value.
Relative error: the percentage of the absolute error in true value.
Quoted error: the percentage of absolute error in meter range.

2.1.2 Conversion error and accuracy grade correction. The various physical variables measured by the field transmitters are transmitted through the 4-20mA current analog signal. When these analog signals are A/D converted in the control system the errors occur. Especially when bit of A/D conversion is not high, the error is large.

The A/D conversion bit of the pump trial stage is 12. That is, the resolution is $1/2^{12}$. The instrument has an accuracy grade of n. The accuracy grade is the concept of the quoted error. So the up deviation of the A/D conversion error can be calculated like this:

$$\left(1+n/100\right) \times 2^{12}/\left(2^{12}-1\right) - 1 = 0.00025 + 0.0100025n$$

Formula 2-1

The down deviation is calculated like this:

$$1 - (1-n/100)\left(1-1/2^{12}\right) = 0.003 + 0.01n$$

Formula 2-2

The accuracy grade of the instrument can be corrected according to the way. But it needs to be noticed that the accuracy grade of instrument is ranked, there are 0.1, 0.2, 0.35, 0.4, 0.5, 1.0, 1.5, 2.5 etc. The corrected accuracy grade need be in the rank.

Deviation correction of accuracy grade 0.1: The up deviation is 0.00125025, the down deviation is 0.0013. Namely the accuracy grade 0.1 is corrected to 0.2.

Deviation correction of accuracy grade 0.2: The up deviation is 0.0022505, the down deviation is 0.0023. Namely the accuracy grade 0.2 is corrected to 0.35.

Deviation correction of accuracy grade 0.5: The up deviation is 0.00525125, the down deviation is 0.0053. Namely the accuracy grade 0.5 is corrected to 1.0.

2.2 Error transfer
During actual measure process, not all physical variables are measured directly. This involves indirect measure. That is, a physical variable cannot be measured directly, but a function of direct measure physical variables. It’s usually a function of multiple variables. The multivariate function can be expressed simply as:

$$y = f(x_1, x_2, \ldots, x_n)$$

In the formula, $x_1, x_2, \ldots, x_n$ are the variables that are measured directly and $y$ is the variable that is measured indirectly, which is the function of the direct measure variables.

Expand the function according to Taylor series:

$$\Delta y = \frac{\partial f}{\partial x_1} \Delta x_1 + \frac{\partial f}{\partial x_2} \Delta x_2 + \cdots + \frac{\partial f}{\partial x_n} \Delta x_n$$

or

$$\Delta y = \sum_{i=1}^{n} \frac{\partial f}{\partial x_i} \Delta x_i$$

Formula 2-3

Formula 2-4

The maximum absolute error is

$$\Delta y = \sum_{i=1}^{n} \left|\frac{\partial f}{\partial x_i} \Delta x_i\right|$$

Formula 2-5

The relative error is

$$\delta = \frac{\Delta y}{y} = \frac{\partial f}{\partial x_1} \frac{\Delta x_1}{y} + \frac{\partial f}{\partial x_2} \frac{\Delta x_2}{y} + \cdots + \frac{\partial f}{\partial x_n} \frac{\Delta x_n}{y} = \frac{\partial f}{\partial x_1} \delta_1 + \frac{\partial f}{\partial x_2} \delta_2 + \cdots + \frac{\partial f}{\partial x_n} \delta_n$$

Formula 2-6

In the error analysis, the formula 1-5 and 1-6 express the error transfer process of direct measure errors of physical variables to indirect measure error of the physical variable.
3. Theoretical error analysis of pump hydraulic performance

A pump is tested on the pump trial stage for its hydraulic performance. The hydraulic performance includes the three items mainly: flow rate, head and hydraulic efficiency. Among them the flow rate is measured directly through the electromagnetic flowmeter, which is a direct measure physical variable. Its error is determined by the accuracy grade of the electromagnetic flowmeter. However the head and the hydraulic efficiency are indirect measure physical variables and their errors need to be analyzed by the error transfer formula.

The head of the pump is calculated in the following formula:

$$H_s=(P_2-P_1+P_a)\times10^6/\rho_s g + \Delta Z + \Delta v; \ (m)$$  

Formula 3-1

In the formula, $P_2$ is the pump outlet pressure, the gauge pressure, unit MPa; $P_1$ is the pump inlet pressure, the absolute pressure, unit MPa; $P_a$ is the atmospheric pressure, the absolute pressure, unit MPa; $\Delta Z$ is difference of pressure gauge height, unit m. Once the trial pump is installed on the pump trial stage, this value is fixed.

In the formula, $\rho$ is the density of water, unit kg/m$^3$. The density of water is a function of temperature $T$ and its function is

$$\rho=1000.03116+0.001843*T; 0.00607*T^2+1.7939E-5*T^3, \ 5^\circ C<T<70^\circ C$$  

Formula 3-2

The unit of $T$ is $^\circ C$ and $T$ is water temperature in the trial pump inlet.

In the formula, $\Delta Z$ is the pressure loss between the trial pump inlet and outlet annulus piezometric chamber, the calculation formula is

$$\Delta Z = (v_2^2-v_1^2)/2g, \ v_2=Q_c/((\pi/4)*\Delta d_2^2*3600), \ v_1=Q_c/((\pi/4)*\Delta d_1^2*3600);$$

In the formula, $\Delta d_2, \Delta d_1$ are the inside diameter of outlet and inlet annulus piezometric chamber, unit m; $Q_c$ is flow rate of the trial pump, unit m$^3$/h.

Expand the pump head formula according to Taylor series:

$$\Delta H_s = \frac{\partial f}{\partial p_2}\Delta p_2 + \frac{\partial f}{\partial p_1}\Delta p_1 + \frac{\partial f}{\partial \rho_s}\Delta \rho_s + \frac{\partial f}{\partial \Delta \rho_s}\Delta \rho_s + \frac{\partial f}{\partial Q_c}\Delta Q_c$$

Formula 3-3

$$= \frac{10^6}{\rho_s g} \Delta p_2 - \frac{10^6}{\rho_s g} \Delta p_1 + \frac{10^6}{\rho_s g} \Delta \rho_s - \frac{10^6}{\rho_s g} \Delta \rho_s + \frac{Q_c}{7986276} \frac{1}{\Delta d_2^2} - \frac{1}{\Delta d_1^2} \Delta Q_c$$

$$\rho_s$$ is a function of temperature and expand $\rho_s$ according to Taylor series:

$$\Delta \rho_s = (0.01843 - 0.01214*T_i + 0.000053817*T_i^2)\Delta T_i$$  

Formula 3-4

Substitute $\rho_s$ into $\Delta H_s$ and collate:

$$\Delta H_s = \frac{10^6}{\rho_s g} \Delta p_2 - \frac{10^6}{\rho_s g} \Delta p_1 - \frac{10^6}{\rho_s g} \Delta \rho_s + \frac{Q_c}{7986276} \frac{1}{\Delta d_2^2} - \frac{1}{\Delta d_1^2} \Delta Q_c$$

Formula 3-5

There is another important performance indicator other than the flow rate, the head of pump: hydraulic efficiency. Hydraulic efficiency of pump is the ratio of pump output power in input power. The output power of pump, that is, the hydraulic power is calculated through the following formula:

$$N_c=Q_c*H_s*\rho/(102*3600); \ (kW)$$  

Formula 3-6

The input power of the pump is usually measured by the torque meter between the motor and the pump. The principle of the torque meter is to measure the output torque and output speed of the motor separately, and then multiply to get the power. Namely:

$$N_c=M*n/9550; \ (kW)$$  

Formula 3-7
In the formula, \( M \) is the output torque of the motor, unit \( N \cdot m \); \( n \) is the motor speed, unit rpm.

The efficiency of the pump is

\[
\eta = \frac{N_s}{N_e} = 0.026 \frac{Q_c \cdot H_s \cdot \rho_s}{(M \cdot n)}; \tag{3-8}
\]

Expand the efficiency formula according to Taylor series:

\[
\Delta \eta = \frac{0.026Q_c \cdot H_s \cdot \rho_s}{Mn} \Delta Q_c + \frac{0.026Q_c \cdot H_s \cdot \rho_s}{Mn} \Delta H_s + \frac{0.026Q_c \cdot H_s \cdot \rho_s}{Mn} \Delta \rho_s - \frac{0.026Q_c \cdot H_s \cdot \rho_s}{Mn} \Delta M - \frac{0.026Q_c \cdot H_s \cdot \rho_s}{Mn} \Delta \rho_s. \tag{3-9}
\]

4. Error analysis of trial data of pump hydraulic performance

A pump is selected to run stably at a certain flow point on the pump trial stage. The trial data is sampled every 30 seconds and a total of 15 samples. Then confirm whether the sampled data fluctuation is in line with expectation. A total of three flow points are selected for observation.

4.1 Accuracy grade and theoretical error of instrument

On trial the measure range and the accuracy grade of the instruments on the pump trial stage are shown as follow:

| Name                          | Code     | Measure Range | Original Accuracy Grade | Corrected Accuracy Grade | Corrected Accuracy Error | Remark            |
|-------------------------------|----------|---------------|-------------------------|--------------------------|--------------------------|-------------------|
| Pump inlet pressure transmitter | P₁       | 0-1MPa        | 0.2                     | 0.35                     | 0.0035MPa               | Absolute pressure |
| Pump outlet pressure transmitter | P₂       | 0-5MPa        | 0.2                     | 0.35                     | 0.0175MPa               | Gauge pressure    |
| Pump inlet water temperature transmitter | T        | 0-100℃       | 0.1                     | 0.2                      | 0.2℃                    |                   |
| Atmospheric pressure transmitter | P₄       | 0-0.11MPa     | 0.25                    | 0.35                     | 0.000385MPa            | Absolute pressure |
| Electromagnetic flowmeter     | Q₃       | 2.3-45.2m³/h  | 0.25                    | 0.35                     | 0.1582m³/h              |                   |
| Tachometer                    |          | 0-3600rpm     | 0.2                     | 0.35                     | 12.6rpm                |                   |
| Torque meter                  |          | 0-100Nm       | 0.3                     | 0.35                     | 0.35Nm                 |                   |

4.2 Trial state 1

Calculate the error at the point of the flow rate 4.3 m³/h, head 168m, inlet water temperature 15.1℃ of pump.

Firstly calculate the flow error. The flow is a direct measure physical variable so flow error is the direct error of measure. Namely: \( \Delta Q_c = \pm 0.1582 \) m³/h. How to apprehend the error? Assume that the true value of the flow is \( Q_c \), the maximum of the flow measure is \( Q_c + 0.1582 \), the minimum is \( Q_c - 0.1582 \). The true value \( Q_c \) is unknown, but the difference between the maximum and the minimum is known as \((Q_c + 0.1582) - (Q_c - 0.1582) = 0.3164\), that is, the error bandwidth is 0.3164 m³/h. The flow values of repeated measure change frequently, but the difference between any two of them should not exceed this range. This means that the trial data can be obtained accurately on the pump trial stage. However, if the difference exceed the range, there must be trouble in some aspects such as electromagnetic interference, the verification of instrument, even the calculation method and the analytical method.

The error of other performance is also interpreted in this way.

Secondly calculate the head error. The head error is calculated through the formula 2-3. There are five items totally in formula 2-3. Respectively calculate the values of these five items and then add them.
so that the value of each item is clear.

### Table 2. Trial state 1 head error items

| No. | 1  | 2  | 3  | 4  | 5  |
|-----|----|----|----|----|----|
| Items | $\frac{10^6}{\rho_s \Delta \rho_{2}}$ | $\frac{10^6}{\rho_s \Delta \rho_{3}}$ | $\frac{10^6}{\rho_s \Delta \rho_{4}}$ | $(\rho_2 - \rho_s + \rho_3)10^6$ | $\frac{Q}{7986276 \cdot (\frac{1}{\Delta d_2} - \frac{1}{\Delta d_3})} \Delta Q_c$ |
| Values | 1.78 | 0.3 | 0.03 | 0.005 | 0.0002 |

The sum of the five absolute values of the head error is $1.787 \pm 0.357 + 0.00302 + 0.000007 + 0.00269 + 0.00109 = 0.0153$, so that the value of each item is clear.

Finally, calculate the efficiency error. The efficiency error is calculated through the formula 2.9. There are five items totally in formula 2.9. Respectively calculate the values of these five items and then add them so that the value of each item is clear.

### Table 3. Trial state 1 efficiency error items

| No. | 1  | 2  | 3  | 4  | 5  |
|-----|----|----|----|----|----|
| Items | $\frac{0.026Q_c \cdot \rho_s \Delta Q_c}{Mn}$ | $\frac{0.026Q_c \cdot \rho_s \Delta H_s}{Mn}$ | $\frac{0.026Q_c \cdot H_s \cdot \rho_s \Delta Q_c}{Mn}$ | $\frac{0.026Q_c \cdot H_s \cdot \rho_s \Delta M}{Mn}$ |
| Values | 0.00854 | 0.00302 | 0.000007 | 0.00269 | 0.00109 |

The sum of the five absolute values of the efficiency is $0.00854 + 0.00302 + 0.000007 + 0.00269 + 0.00109 = 0.0153$, that is, the error bandwidth of the efficiency is 0.0306.

A total of 15 sets of data are obtained on trial, as shown in the following table:

### Table 4. Trial state 1 trial data

| No. | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|-----|----|----|----|----|----|----|----|----|----|----|
| Flow(m³/h) | 4.336 | 4.336 | 4.336 | 4.336 | 4.336 | 4.336 | 4.336 | 4.336 | 4.336 | 4.336 |
| Head(m) | 168.14 | 168.14 | 168.580 | 167.993 | 167.993 | 166.57 | 168.727 | 168.583 | 167.997 | 168.14 |
| Torque(Nm) | 30.216 | 30.4 | 30.177 | 30.096 | 30.177 | 30.096 | 30.232 | 30.096 | 30.177 |
| Speed(rpm) | 2676.0 | 2677.061 | 2679.138 | 2679.138 | 2679.138 | 2679.138 | 2679.138 | 2679.138 | 2679.138 |
| Efficiency | 0.2342 | 0.2318 | 0.2349 | 0.2361 | 0.2350 | 0.2358 | 0.2356 | 0.2350 | 0.2350 | 0.2350 |

Firstly analyze the error range of the flow.

The serial number of the smallest flow is 2, 12, 14, 15 and the minimum is 4.323.

The serial number of the largest flow is 4, 8, 11 and the maximum is 4.363.

The difference between the maximum and the minimum is 4.363-4.323=0.04, which is within the expected error bandwidth of 0.3164, in line with expectation.

Secondly analyze the error range of the head.

The serial number of the smallest head is 4 and the minimum is 167.993.

The serial number of the largest head is 6 and the maximum is 168.727.

The difference between the maximum and the minimum is 168.727-167.993=0.734, which is within the expected error bandwidth of 4.376, in line with expectation.

Finally analyze the error range of the efficiency.

The serial number of the smallest efficiency is 2 and the minimum is 0.2318.

The serial number of the largest efficiency is 11 and the maximum is 0.2363.
The difference between the maximum and the minimum is 0.2363-0.2318=0.0045, which is within the expected error bandwidth of 0.0306, in line with expectation.

4.3 Trial state 2

Calculate the error at the point of flow rate 12m³/h, head 178m, inlet water temperature 15.36℃ of pump.

Firstly calculate the flow error. Flow is a direct measure physical variable and the flow error is direct error of measure. The flow error \( \Delta Q_c = \pm 0.1582 \text{m}^3/\text{h} \), that is, the error bandwidth is 0.3164 m³/h.

Secondly calculate the head error. The head error is calculated through the formula 2-3. There are five items totally in formula 2-3. Respectively calculate the values of these five items and then add them so that the value of each item is clear.

| No. | 1    | 2    | 3    | 4    | 5    |
|-----|------|------|------|------|------|
| Items | \( \frac{10^6}{\rho_5 g} \Delta P_2 \) | \( \frac{10^6}{\rho_5 g} \Delta P_h \) | \( \frac{10^6}{\rho_5 g} \Delta P_3 \) | \( \frac{(p_5 - p_6 + p_3)10^6}{\rho_5 g} \Delta P_3 \) | \( \frac{Q_c}{7986276g} \left( \frac{1}{\Delta d_2^2} - \frac{1}{\Delta d_1^2} \right) \Delta Q_c \) |
| Values | 1.78 | 0.3  | 0.03 | 0.005 | 0.0005 |

The sum of the five absolute values of the head error is 1.787+0.357+0.039+0.005+0.0005=2.1885, that is, the error bandwidth of the head is 4.377m.

Finally calculate the efficiency error. The efficiency error is calculated through the formula 2-9. There are five items totally in formula 2-9. Respectively calculate the values of these five items and then add them so that the value of each item is clear.

| No. | 1    | 2    | 3    | 4    | 5    |
|-----|------|------|------|------|------|
| Items | \( \frac{0.026Q_c * \rho_5}{Mn} \Delta Q_c \) | \( \frac{0.026Q_c * \rho_5}{Mn} \Delta H_h \) | \( \frac{0.026Q_c * H_s * \rho_5}{Mn} \Delta M_3 \) | \( \frac{0.026Q_c * H_s * \rho_3}{Mn} \Delta M_4 \) | \( \frac{0.026Q_c * H_s * \rho_3}{Mn} \Delta M_5 \) |
| Values | 0.0061 | 0.00568 | 0.00001 | 0.00359 | 0.00218 |

The sum of the five absolute values of the efficiency error is 0.0061+0.00568+0.00001+0.00359+0.00218=0.0175, that is, the error bandwidth of the efficiency is 0.035.

A total of 15 sets of data are obtained on trial, as shown in the following table:

| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|-----|---|---|---|---|---|---|---|---|---|----|
| Flow(m³/h) | 12.041 | 12.054 | 11.988 | 11.988 | 12.067 | 12.041 | 12.002 | 12.067 | 11.975 | 12.041 |
| Head(m) | 178.01 | 178.01 | 178.16 | 178.01 | 178.01 | 178.16 | 178.16 | 178.15 | 177.72 |
| Torque(Nm) | 45.203 | 45.098 | 45.078 | 45.097 | 45.079 | 45.223 | 45.203 | 44.998 | 45.212 |
| Speed(rpm) | 2665.6 | 2664.6 | 2665.6 | 2664.6 | 2665.6 | 2665.6 | 2665.6 | 2665.6 | 2665.6 |
| Efficiency | 0.4620 | 0.4637 | 0.4616 | 0.4612 | 0.4642 | 0.4632 | 0.4606 | 0.4633 | 0.4619 | 0.4611 |

Firstly analyze the error range of the flow.
The serial number of the smallest flow is 12 and the minimum is 11.949.
The serial number of the largest flow is 5,8,11 and the maximum is 12.067. The difference between the maximum and the minimum is 12.067-11.949=0.118, which is within the expected error bandwidth of 0.3164, in line with expectation.

Secondly analyze the error range of the head. The serial number of the smallest head is 10 and the minimum is 177.722. The serial number of the largest head is 7, 8 and the maximum is 178.162. The difference between the maximum and the minimum is 178.162-177.722=0.44, which is within the expected error bandwidth of 4.377, in line with expectation.

Finally analyze the error range of the efficiency. The serial number of the smallest efficiency is 12 and the minimum is 0.4596. The serial number of the largest efficiency is 5 and the maximum is 0.4642. The difference between the maximum and the minimum is 0.4642-0.4596=0.0046, which is within the expected error bandwidth of 0.035, in line with expectation.

4.4 Trial state 3

Calculate the error at the point of flow rate 16 m³/h, head 212m, inlet water temperature 15.65℃ of pump.

Firstly calculate the flow error. Flow is a direct measure physical variable and the flow error is direct error of measure. The flow error $\Delta Q_C=\pm 0.1582m³/h$, that is, the error band width is 0.3164 m³/h.

Secondly calculate the head error. The head error is calculated through the formula 2-3. There are five items totally in formula 2-3. Respectively calculate the values of these five items and then add them so that the value of each item is clear.

Finally calculate the efficiency error. The efficiency error is calculated through the formula 2-3. Respectively calculate the values of these five items and then add them so that the value of each item is clear.

| Table 8. Trial state 3 head error items |
|----------------------------------------|
| No. | 1 | 2 | 3 | 4 | 5 |
| Items | $10^6 \frac{\Delta p_2}{\rho_s g}$ | $10^6 \frac{\Delta p_1}{\rho_s g}$ | $10^6 \frac{\Delta p_s}{\rho_s g}$ | $\frac{(\rho_s - p_s + p_e)10^6}{\rho_s g}$ | $\frac{Q}{7986276g} \left( \frac{1}{\Delta d_s^2} - \frac{1}{\Delta d_i^2} \right) \Delta Q_C$ |
| Values | 1.787 | 0.357 | 0.039 | 0.006 | 0.0006 |

The sum of the five absolute values of the head error is $1.787+0.357+0.039+0.006+0.0006=2.1896$, that is, the error bandwidth of the head is 4.3792m.

Finally calculate the efficiency error. The efficiency error is calculated through the formula 2-9. There are five items totally in formula 2-9. Respectively calculate the values of these five items and then add them so that the value of each item is clear.

| Table 9. Trial state 3 efficiency error items |
|-----------------------------------------------|
| No. | 1 | 2 | 3 | 4 | 5 |
| Items | $\frac{0.026H_s \ast \rho_s \Delta Q_C}{Mn}$ | $\frac{0.026Q_e \ast \rho_s \Delta H_s}{Mn}$ | $\frac{0.026Q_e \ast H_s \ast \rho_s \Delta H_s}{Mn}$ | $\frac{0.026Q_e \ast Q_s \ast \rho_s \Delta M}{M^2n}$ | $\frac{0.026Q_e \ast Q_s \ast H_s \ast \rho_s \Delta n}{M^2n}$ |
| Values | 0.00493 | 0.00515 | 0.00001 | 0.00291 | 0.00214 |

The sum of the five absolute values of the efficiency error is $0.00493+0.00515+0.00001+0.00291+0.00214=0.0151$, that is, the error bandwidth of the efficiency is 0.0302.

A total of 15 sets of data are obtained on trial, as shown in the following table:

| Table 10. Trial state 3 trial data |
|-----------------------------------|
| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Flow(m³/h) | 15.952 | 16.018 | 15.979 | 16.018 | 16.018 | 15.952 | 16.005 | 16.005 | 16.057 | 16.044 |
| Head(m) | 212.471 | 212.179 | 212.184 | 212.184 | 212.184 | 212.184 | 212.184 | 212.184 | 212.184 | 212.184 |
| Torque(Nm) | 60.256 | 60.323 | 60.276 | 60.276 | 60.276 | 60.276 | 60.276 | 60.276 | 60.276 | 60.276 |
| Speed(rpm) | 2940.774 | 2939.73 | 2939.73 | 2939.73 | 2939.73 | 2940.77 | 2940.77 | 2939.73 | 2940.77 | 2940.77 |
| Efficiency | 0.4967 | 0.4977 | 0.4973 | 0.4981 | 0.4981 | 0.4969 | 0.4985 | 0.4975 | 0.4996 | 0.4991 |
Firstly analyze the error range of the flow.

The serial number of the smallest flow is 6, 14 and the minimum is 15.952.
The serial number of the largest flow is 9 and the maximum is 16.057.
The difference between the maximum and the minimum is
16.057-15.952=0.105, which is within the expected error bandwidth of 0.3164, in line with expectation.

Secondly analyze the error range of the head.
The serial number of the smallest head is 14 and the minimum is 211.894.
The serial number of the largest head is 7 and the maximum is 212.479.
The difference between the maximum and the minimum is 212.479-211.894=0.585, which is within the expected error bandwidth of 4.3792, in line with expectation.

Finally analyze the error range of the efficiency.
The serial number of the smallest efficiency is 14 and the minimum is 0.4952.
The serial number of the largest efficiency is 9 and the maximum is 0.4996.
The difference between the maximum and the minimum is 0.4996-0.4952=0.0044, which is within the expected error bandwidth of 0.0302, in line with expectation.

4.5 Trial conclusion

Through the analysis of the three sets of trial data, some conclusions are brought as follows:

1. The data fluctuation of flow measure, head measure and efficiency measure obtained on the pump trial stage is in the range of theoretical error expected. At least this shows that there is no trouble with anti-electromagnetic interference, accurate verification and grade determination of instruments, verification data application of instruments in the control system and hydraulic performance analysis of pump, which shows the ability of stable trial data acquirement on the pump trial stage. In other words, the hydraulic performance data of the trial pump is reliable and credible on the pump trial stage.

2. In API610, head error of pump is required within ± 3%, efficiency error of pump is required within ± 2.5%. The theoretical error of head and efficiency on the pump trial stage can meet the requirement. The measured error is far less than the value required in API610, so data of head and efficiency on the pump trial stage can meet the accuracy requirement in API610 when pump is left out of factory.

5. The method of reducing error

1. Improve accuracy grade, reduce absolute error of instrument;
   With the same coefficient the absolute error of instrument is smaller and the absolute error of the transfer function is also smaller, which is obvious from the error transfer formula.

2. Adopt high bit A/D conversion, reduce A/D conversion error;

3. Reduce length of measure chain, reduce the superposition number of absolute error;
   It is known from the error transfer formula that there are several instruments and there is the same number of superposition transmission error. If the number of instruments decreases, the number of transmission error will decrease and the total error will shrink. For example, head is calculated here that outlet pressure of pump (gauge pressure) minus inlet pressure of pump (absolute pressure) then plus atmospheric pressure (absolute pressure). In this way, error of head includes errors of these three instruments. If measured by a differential pressure transmitter, error of head includes only one instrument transmission error. Then error of head is much smaller.

4. During measure process, select the appropriate instrument that the measure range is close
possibly to the measure valve, not large measure range to small value;
For example, to measure the flow rate, once the flowmeter is determined, the absolute error of measure is fixed. But the measure value is larger, the relative error of measure is smaller.
The methods above can be obtained from the analysis in the previous chapters.
In fact, in order to reduce the error, other methods need be adopted. Such as to avoid analog signal interference in the transmission, some corresponding anti-interference measures need to be adopted. In order to reduce the conversion error, the high bit A/D conversion even digital transmission can be adopted. These methods can reduce error and improve measure accuracy.

6. Concluding remark
Based on the theoretical analysis of the pump hydraulic performance, the error transfer formula of flow, head and efficiency of the pump are obtained. Combined with the theoretical analysis formula, the selected pump trial has been finished on the pump trial stage and the trial data meets the demand expected. This shows that the theoretical analysis and the trial data obtained on the pump trial stage are reliable, which reflects the excellent ability of trial data acquirement on the pump trial stage.

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