The Study on the Measurement & Testing Technology of the HMCVT Hydraulic Pressure Based on the Data Fusion Technology

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Abstract. The pressure of the hydro-mechanical continuously variable transmission (HMCVT) is not only one of the major factors affecting the performance of the power train but also the major control parameter of the HMCVT control system. So how to improve the high accuracy hydraulic pressure parameter for the HMCVT control system will be one of the key technologies in system development. Based on the HMCVT test system for a certain tracked vehicle, the hydraulic pressure is studied, and multi-sensor data fusion technology based on Taylor polynomial regression equation is put forward, which turn out to improve the performance of the pressure sensor. Utilizing the above-mentioned method, the ability of anti-jamming of the hydraulic screen pressure system of the HMCVT is effectively improved, and the validity of the test data in the test system is improved too.

1. Introduction

The hydraulic mechanical continuous variable transmission (HMCVT) is a new type of dual-power (hydro-pressure and mechanics) transmission system [1]. The transmission scheme of the hydrostatic mechanical transmission of one type of tracked vehicles is shown in figure 1. One route of power passes by variable pump and fixed motor, the other one passes by the planetary gear. The power transferred by the hydraulic transmission is continuous variable with the displacement of the variable pump. The power transmission by the mechanic transmission is natural change. By controlling the joint and separate of the clutch and combing the hydraulic transmission, the continuous transmission can be realized.

As is shown in figure 1, the joint and separate of the clutch is completed by controlling the cylinder through the hydraulic transmission [2]. So in this transmission system, not only in the hydraulic power route but also in the mechanic power route, the pressure in the hydraulic system is one of the main factors that influence the performance of the system. Based on the above reason, how to improve the high accuracy pressure parameters to the control system of the hydraulic continuous transmission system is the key technology in the technology development.

The output of the system pressure sensor is not only controlled by the value of inputted pressure, but also the variety of the working temperature and the fluctuation of the power supply. It is indicated through the investigations and applications in our country and abroad by using the multi-sensor data fusion technology, the uncertainty factor in the test can be valid eliminated, the accuracy in the testing
The multi-sensor data fusion technology is a new technology in the intelligent inspection information processing. By using this technology in the pressure test in the transmission system, the performance in the test system is validly improved. The system has the characters of the expert system. The parameters accuracy after the data fusion refinement can be significantly improved.

2. Theory of the data fusion

2.1. The basis theory of the data fusion

The data fusion is also called multi-sensor data fusion. Its basis theory is to make full use of multi-sensor source, through the rational charge and application to the test information of the sensors, the redundancy information or complementary information in spatial and temporal with one kind of algorithm is been composed, the consistency interpretation or description to the implementation under test is produced. Based on the separate measuring information of every sensor, through the optimization and combination to the information, more useful information can be got by using the multi-sensor data fusion technology. In this paper, by using the extraction advantage of multi-sensor, the efficiency to the whole sensors system is improved, the limitation to single or few sensors is eliminated, the more advanced feature than every subsystem in the sensors system can be got.

2.2. The data fusion course

The basis data fusion processing is shown in figure 2.

Because most of the implementation under test is non-electric with different characters, such as oil pressure and oil temperature in the hydraulic system of the HMCVT. So first the non electric signals must be transferred to the electric signals, then been transferred to the digital data through the A/D conversion, the pretreatment to the electric signals after digitization are been outlier culled and decomposition trend eliminated and signal smooth processed and zero averaged to eliminate the interference and noise during the data acquisition. The signature extracting to the useful signal after pretreatment, the data fusion is done, the result is output.

3. Data fusion algorithm analysis on the pressure test of the HMCVT hydraulic system

The performance test of the HMCVT including the efficiency of the hydraulic circuit, the shift quality of the power transmission, so the pressure test on the variable pump and fixed motor of the hydraulic circuit and the oil circuit control pressure of every sensor must be carried out. Because the hydraulic oil temperature will change during the power transmission, the output of the pressure sensor will be influenced by the changing of the ambient temperature and the voltage fluctuation of the supply power for the sensors, the influence to the pressure sensors should be eliminated. During the working course of the power transmission, the oil temperature will influence its own quality, so the oil temperature...
must be monitored and controlled. The test for voltage fluctuation is easy to electric control system. It has excellent hardware foundation by using the data fusion technology for the pressure test of the HMCVT test engineering.

3.1. The fusion principle of the pressure sensor
The reasonable fusion principle during the multi-sensor fusion must be set up. Before the fusion system is set up, the calibration to the sensors while the environment variables should be carry out in order to eliminate the influence from the unfavorable environment.

The output characteristic of pressure sensor for HMCVT hydraulic system may express as the following fitting function formula (hydraulic oil pressure: \( p \); ambient temperature: \( t \); supply voltage of sensor: \( u_k \)):

\[
u_o = f(p,t,u_k)
\]

The sensor output is expressed as the Taylor series expansion with multivariate function.

\[
u_o = \beta_0 + \beta_1 p + \beta_2 t + \beta_3 u_k + \beta_4 p^2 + \beta_5 t^2 + \beta_6 u_k^2 + \beta_7 p t + \beta_8 p u_k + \beta_9 t u_k + o(p^2)
\]

Where \( \beta_0, \beta_1, \ldots, \beta_9 \) is undermined coefficients; \( \rho = \text{sqr}(p^2 + t^2 + u_k^2) \), if \( \rho \rightarrow 0, o(p^2) \) is advanced infinitely small, the approximate value is zero.

In order to set up the fitting regression equation, the undermined coefficients \( \hat{\beta}_0, \hat{\beta}_1, \ldots, \hat{\beta}_9 \) are to be solved, so with the results the calibration test under different temperature and supply voltage process of the pressure sensor, we can obtain fitting regression equation

\[
\hat{u}_o = \hat{\beta}_0 + \hat{\beta}_1 p + \hat{\beta}_2 t + \hat{\beta}_3 u_k + \hat{\beta}_4 p^2 + \hat{\beta}_5 t^2 + \hat{\beta}_6 u_k^2 + \hat{\beta}_7 p t + \hat{\beta}_8 p u_k + \hat{\beta}_9 t u_k
\]

Where \( \hat{u}_o \) can optimal represent oil circuit pressure \( \hat{\beta}_0, \hat{\beta}_1, \ldots, \hat{\beta}_9 \) are undermined coefficients, are estimate value of \( \hat{\beta}_0, \hat{\beta}_1, \ldots, \hat{\beta}_9 \).

According to the equation-least squares method, the most excellent estimating value-the undermined coefficient \( \hat{\beta}_0, \hat{\beta}_1, \ldots, \hat{\beta}_9 \) of one pressure value is determined and the surplus square sum Q is the minimum value.

\[
Q = \sum_{i=1}^{n}(u_{oi} - \hat{u}_{oi})^2 = \sum_{i=1}^{n}[u_{oi} - (\hat{\beta}_0 + \hat{\beta}_1 p_i + \hat{\beta}_2 t_i + \hat{\beta}_3 u_{ki} + \hat{\beta}_4 p_i^2 + \hat{\beta}_5 t_i^2 + \hat{\beta}_6 u_{ki}^2 + \hat{\beta}_7 p_i t_i + \hat{\beta}_8 p_i u_{ki} + \hat{\beta}_9 t_i u_{ki})]^2
\]

In order the Q value to gets the minimum value, the derivation calculus to \( \hat{\beta}_0, \hat{\beta}_1, \ldots, \hat{\beta}_9 \) should be done separately and make the values all are zero, as

\[
\begin{bmatrix}
\sum_{i=1}^{n}p_i & \sum_{i=1}^{n}t_i & \sum_{i=1}^{n}u_{ki} & \sum_{i=1}^{n}p_i^2 & \sum_{i=1}^{n}t_i^2 & \sum_{i=1}^{n}u_{ki}^2 & \sum_{i=1}^{n}p_i t_i & \sum_{i=1}^{n}p_i u_{ki} & \sum_{i=1}^{n}t_i u_{ki}
\end{bmatrix}
\begin{bmatrix}
\hat{\beta}_0 \\
\hat{\beta}_1 \\
\hat{\beta}_2 \\
\hat{\beta}_3 \\
\hat{\beta}_4 \\
\hat{\beta}_5 \\
\hat{\beta}_6 \\
\hat{\beta}_7 \\
\hat{\beta}_8 \\
\hat{\beta}_9
\end{bmatrix}
= \begin{bmatrix}
\sum_{i=1}^{n}u_{oi}
\end{bmatrix}
\]

Solve matrix,

\[
\hat{\beta} = \begin{bmatrix}
\hat{\beta}_0 \\
\hat{\beta}_1 \\
\vdots \\
\hat{\beta}_9
\end{bmatrix}^T = \begin{bmatrix}
\frac{1}{n} \sum_{i=1}^{n}u_{oi} \\
\frac{1}{n} \sum_{i=1}^{n}p_i u_{oi} \\
\frac{1}{n} \sum_{i=1}^{n}t_i u_{oi}
\end{bmatrix}
\]

3.2. The significance test of the fitting regression equation
The fitting regression equation is a hypothesis of the pressure is influenced by the environment factors, the statistical properties test is carried out to the equation to ensure the reliability of the equation.
Suppose the equation (7) is the fitting regression equation that is solved, the \( \hat{u}_{oi} \) is the fitting value of the \( i \)th pressure test dot, then

\[
\begin{bmatrix}
\hat{u}_{o0} \\
\hat{u}_{o1} \\
\vdots \\
\hat{u}_{on}
\end{bmatrix} = \begin{bmatrix}
1 & p_0 & t_0 & u_{t0} & p_0^2 & t_0^2 & u_{t0}^2 & p_0 t_0 & p_0 u_{t0} & t_0 u_{t0} \\
1 & p_1 & t_1 & u_{t1} & p_1^2 & t_1^2 & u_{t1}^2 & p_1 t_1 & p_1 u_{t1} & t_1 u_{t1} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
1 & p_n & t_n & u_{tn} & p_n^2 & t_n^2 & u_{tn}^2 & p_n t_n & p_n u_{tn} & t_n u_{tn}
\end{bmatrix}
\begin{bmatrix}
\hat{\beta}_0 \\
\hat{\beta}_1 \\
\vdots \\
\hat{\beta}_9
\end{bmatrix}
\tag{7}
\]

After the power assessment to the equation (7), the square sum of dispersion of the testing pressure value can be got.

\[
l_{uu} = \sum_{i=1}^{n} u_{oi}^2 - \frac{1}{n} \left( \sum_{i=1}^{n} u_{oi} \right)^2
\tag{8}
\]

Its degree of freedom is \( f = n-1 \).

Decomposition the square sum of dispersion \( l_{uu} \) to two parts: one is the regression square-sum \( U \) which is caused by the environment factors and the other is the surplus square-sum \( Q \) which is caused by the testing error and other factors. Where:

\[
U = \sum_{i=1}^{n} \left[ \hat{u}_{oi} - \frac{1}{n} \left( \sum_{i=1}^{n} \hat{u}_{oi} \right) \right]^2, \quad f_U = 9
\tag{9}
\]

\[
Q = \sum_{i=1}^{n} (u_{oi} - \hat{u}_{oi})^2, \quad f_Q = n - 9 - 1
\tag{10}
\]

The level of significance value \( \alpha \) in the fitting equation is selected, the statistic \( F \) is worked out:

\[
F = \frac{(U/f_U)/(Q/f_Q)}{(U/f_U)/(Q/f_Q)} \tag{11}
\]

Then according to the first DOF (degree of freedom) \( f_U \) and the second DOF \( f_Q \) the \( F^{\alpha}_{(f_U,f_Q)} \) value can be checked out. Compare the value \( F^{\alpha}_{(f_U,f_Q)} \) and the value \( F \) to sure its significance ability, to much remarkable estimation, the fitting regression equation is valid. Then the real-time testing fusion algorithm -the fitting function equation of the pressure sensors is established.

4. The pressure test data registration of the HMCVT

When the data fusion calculation in the test system is done, the measured value must be the value for synchronization. While the data sampling is carried out in the real test system, because of the properties difference and the frequency difference among every physical quantity, the data sampling frequency is also difference. The time registration to every value measured should carried out to make the parameters be the value for synchronization when the data fusion is done.

The asynchronous problem caused by the data sampling frequency difference among every parameter can be corrected by the Taylor correction method and the interpolation method and the virtual data fusion method. In the hydraulic system of the HMCVT, the temperature varies slower, the voltage fluctuation varies faster, so the high frequency and synchronous sampling is used to the temperature and the pressure and the voltage fluctuation. When the pretreatment is done to the sampling signal in the system, for example, the data missing will happened when the outliner is culled, the missing data will be corrected with the three-point interpolation method.

5. The practical analysis of the pump pressure test in the HMCVT

Before the fusion principles usage to the above data, the output voltage test of one kind of pressure sensor that is used in the hydraulic system is tested under difference temperature and difference voltage. The pressure range of the sensor is 0~60Mpa, the range of the working environments is -20~80°C, the range of the media temperature is -40~125°C, the power supply standard is 24VDC. In the test, the adjustment precision resistor circuit is adopted. In the same time, the test is carried out in the constant environment. \( P \) represents the oil pressure, \( U_0 \) represents the output of the pressure sensor,
t represents the oil temperature tested, $U_i$ represents the power supply voltage of the pressure sensor, it also responds the supply voltage fluctuation of the sensor. The test result is shown in table 1.

| P/MPa | $t=70^\circ C$ | $t=40^\circ C$ | $t=20^\circ C$ |
|-------|----------------|----------------|----------------|
|       | $U_o/mV$ | $U_i/V$ | $U_o/mV$ | $U_i/V$ | $U_o/mV$ | $U_i/V$ |
| 0     | -0.9543  | 23.046 | -0.9688  | 23.763 | -1.7708  | 24.395 |
| 5     | 12.4731  | 23.113 | 13.4658  | 23.815 | 12.413   | 24.453 |
| 10    | 30.6869  | 23.175 | 30.6804  | 23.866 | 30.6087  | 24.512 |
| 15    | 52.9213  | 23.239 | 50.4255  | 23.931 | 48.8227  | 24.574 |
| 20    | 64.1721  | 23.302 | 70.0983  | 23.964 | 72.0414  | 24.632 |
| 25    | 84.4515  | 23.368 | 87.7555  | 24.065 | 90.2704  | 24.690 |
| 30    | 104.7399 | 23.431 | 107.5178 | 24.065 | 106.5142 | 24.749 |
| 35    | 120.0614 | 23.497 | 121.3263 | 24.208 | 127.7084 | 24.796 |
| 40    | 134.3875 | 23.560 | 140.1804 | 24.274 | 142.8266 | 24.831 |
| 45    | 153.8301 | 23.638 | 160.0209 | 24.331 | 164.0399 | 24.884 |
| 50    | 173.2247 | 23.704 | 174.8176 | 24.386 | 182.4613 | 24.965 |

Under the constant environment condition, the fitting effect is valid by the output of the sensor through the pressure $P$ and the power supply voltage $U_i$.

According to the parameters in Tab.1, the relationship among the output of the pressure sensor $U_o$ and the oil pressure $P$ and the power supply voltage of the pressure sensor $U_i$ is as shown in figure.3. From figure.3, the three parameters are assumed nonlinear relationship. According to the data fusion formula (3), the fusion formula (12) under the voltage fluctuation and the pressure is got.

$$\hat{u}_o = \hat{\beta}_0 + \hat{\beta}_p P + \hat{\beta}_u u_k + \hat{\beta}_p p^2 + \hat{\beta}_u p u_k + \hat{\beta}_u^2 u_k^2$$

(12)

According to the formula (12), substitutes the data in Table.1, the coefficient matrix can be got.

$$\hat{\beta} = [0.2674 \hspace{1cm} 0.0452 \hspace{1cm} -0.006 \hspace{1cm} -0.0015 \hspace{1cm} 0.1472 \hspace{1cm} -0.0006]$$

Thereby the data fusion algorithm (13) is obtained during the course of test processing of this sensor.

$$u_o = -0.2674 + 0.0452 p - 0.006 u_i - 0.0015 p^2 + 0.1472 p u_i - 0.0006 u_i^2$$

(13)

Substitute the pressure and the power supply voltage in Tab.1 to the algorithm (13), the output after the data fusion is got, as is shown in Tab.2. In figure.4, the relationship between the output voltage and pressure and supply voltage after fusion is showed. The nonlinearity of the output of the sensor is obviously improved.

On this basis, the treatment to the output of the sensor under different oil pressure and different media temperature and different power supply voltage is done. The test to the significance of the fitting equation is carried out. According to the regression square-sum U and the surplus square-sum Q and the first DOF (degree of the freedom) $f_1$ and the second DOF $f_0$ and the formula (11), F is calculated 2.7496. The significance level is set as $a=0.025$, according to the first DOF $f_1$ and the second DOF $f_0$, $F^{1}_{(9,23)}=2.73$ is checked out. Because $F>F^{0.025}_{(9,23)}$, the fitting equation is much remarkable, the regression equation is efficiency.
Table 2. The pressure sensor fusion results.

| P/MPa | t=70°C | t=40°C | t=20°C |
|-------|--------|--------|--------|
|       | Uo/mV  | Ui/V   | Uo/mV  | Ui/V   | Uo/mV  | Ui/V   |
| 0     | -0.7243 | 23.046 | -0.7488 | 23.763 | -0.7708 | 24.395 |
| 5     | 16.4731 | 23.113 | 16.9658 | 23.815 | 17.4130 | 24.453 |
| 10    | 33.6869 | 23.175 | 34.6804 | 23.866 | 35.6087 | 24.512 |
| 15    | 50.9213 | 23.239 | 52.4255 | 23.931 | 53.8227 | 24.574 |
| 20    | 68.1721 | 23.302 | 70.0983 | 23.964 | 72.0414 | 24.632 |
| 25    | 85.4515 | 23.368 | 87.7555 | 24   | 90.2704 | 24.690 |
| 30    | 102.7399 | 23.431 | 105.5178 | 24.065 | 108.5142 | 24.749 |
| 35    | 120.0614 | 23.497 | 123.3268 | 24.135 | 126.7084 | 24.796 |
| 40    | 137.3875 | 23.560 | 141.1804 | 24.208 | 144.8266 | 24.831 |
| 45    | 154.8301 | 23.638 | 159.0209 | 24.274 | 163.0399 | 24.884 |
| 50    | 172.2247 | 23.704 | 176.8176 | 24.331 | 181.4613 | 24.965 |

6. Conclusion

Based on the research of the hydraulic pressure in the HMCVT test system for a certain tracked vehicle, the multi-sensor data fusion technology based on Taylor polynomial regression equation is used to improve the performance of the pressure sensor and the pressure test accuracy. By testing, the anti-disturbance of the hydraulic system and the data detection of the test system are effectively improved when this method is adopted.

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References

[1] Zhang Bao-bin, Yuan Shi-hua and Zhao Ran 2003 The study of controlling system for HMCVT Vehicle and Energetics 004 1-3
[2] Zhang Ming-zhu, zhou Zhi-li and Xu Li-you 2003 The design of multiplex HMCVT for agricultural traction Engineagricultural engineering journal 19 118-121
[3] Li Shen-yi, Wu Xue-zhong and Fan Da-peng 1999 Multi-sensor fusion theory and application in intellectual manufacturing system (Changsha: Nudt Press)
[4] He You, Wang Guo-hong and Lu Da-xin 2000 Multi-sensor data fusion and application (Beijing: phei)
[5] Carey W P and Yee S S 1992 Calibration of nonlinear solid-state sensor arrays using multivariate regression models Sensors and Actuators B 9 113
[6] Teng Zhao-sheng, Luo Long-fu and Tong Diao-shen 2000 Intellectual detection system and data fusion (Beijing: Machine Press)
[7] Peng Yan, Xu Yu and Jin Hong-bin 2005 Time registering algorithm analysis in multi-sensor data fusion system Radar and Antagonize 002 16-21