Research on an Automatic Measuring Technique for Mechanical Characteristic in Industrial Circuit Breaker

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Key words: Circuit breaker, servo motor, optical encoder, force sensor, high speed DAQ card

Abstract: This paper describes a development of measuring technique and instrument for mechanical characteristic of industrial circuit breakers. The instrument accomplishes automatically measuring by combining of optical-mechanical-electronic method that is composing of an industrial computer, a servo motor, a precision linear module, a force sensor, a high speed DAQ, measuring and controlling circuits etc. By using LabView programming language, the automatic measuring and controlling software are programmed. In measuring, a series of controlling frequency pulse are transmitted to the servo motor to control it turning by using one port of the PCI-6143 DAQ card in the industrial computer, which drives a work-table on the precision linear module moving. The force sensor on the moving table, which connects to a breaker measured with a testing column, can provide a driving power to the breaker to simulate its working state. Then, the sensor measures the mechanical parameters and force-changing characteristic during the table moving. At the same time, the optical encoder of the servo motor can output corresponding frequency pulses to count the turning angle. The industrial computer reads the pulse counts from a counter of the PCI-6143 DAQ card and the software system can figure out the actual moving distance according to unit displacement represented to every pulse. It can also measure switching working state curve, switching force value, switching force changing process curve and switching synchronization of three-circuit breaker. It can measure many mechanical parameters of one industrial circuit breaker and can also measure many types of industrial circuit breaker. It accomplishes so many functions as automatically measuring, displaying, saving, querying and printing. It has preferable dynamic response characteristic and better measuring precision. Further more, its actual application in aviation circuit breakers proves that the instrument has a favorable measuring effect.

1 Introduction

Industrial circuit breakers play an important role of ensuring electric power safety and realizing automatically controlling. They are more widely applied to industrial equipments, airplanes, ships, vehicles and automatic measuring devices. Their own reliability mainly depends on characteristic of inner mechanical and electrical operation system. The mechanical characteristic is including to some very important technical parameters, which influences its using life and switching capability. The statistic of experimental and practical application exposits, when an industrial circuit breaker cannot normally play its role, the most reason is that its internal mechanical system does not reliably act. In the design, manufacture, assemblage, maintenance and adjustment of breakers, measuring these parameters is absolutely necessary. At present, there are general two ways to measure it. One way, sensors are directly installed on the contact to measure for

on-limits industrial circuit breakers; another way, vibration sensors are used. These two ways, former only can aim at the special breakers, latter cannot obtain the work process information of breakers, and the both measuring results are not comprehensive, the efficiency is low and so on the question. Therefore, one speed measuring technique of mechanical characteristic in industrial circuit breakers and the measuring instrument becomes an urgent need. This present paper bases on a great deal experimental data, through the principle analysis of mechanical characteristics in industrial circuit breakers, takes the intelligent technology of measurement and control as foundation, with the aid of virtual instrument technology, has designed an automatic measuring instrument for the mechanical characteristics in industrial circuit breakers. The instrument has realized measuring automatically and accurately appraised the mechanical characteristics of industrial circuit breakers. The application has provided enormous convenient for the measuring.

2 Some main mechanical characteristic parameters of industrial circuit breakers

(1)Spare journey of a circuit breaker

It is the moving length of a moving contact from starting switching

on to locking up completely.
(2)Switching synchronization of a three-circuit breaker
It is the difference of every spare journey of three paths in a three-circuit breaker.
(3)Switching working state curve
It records the whole dynamic switching electricity process for every contact.
(4)Switching force process curve
It records the dynamic force changing process during a circuit breaker switching.
(5) Switching extreme force
It is the max force during a circuit breaker switching.

3 Measuring theory

Measuring mechanical characteristic in industrial Circuit breaker includes switching on process and switching off process.
(1)The switching-on process: A positive, linear, uniform moving and driving force to push for a circuit breaker measured is provided by using an industrial computer controlling a servo motor, a precision linear module and a testing column. Then, a voltage pulse signal can be measured with a voltage sensor and a DAQ card when the circuit breaker switches on; the starting position can be got by using a optical encoder during every path switching on; the push force is measured with a force sensor and the DAQ card, with which the dynamic changing curve of the force, the switching-on force and the locking force during switching-on process is acquired. When the force changing curve is up to the setting threshold, the circuit breaker is regarded as locked and every path locking position is got by using the optical encoder. Subtracting starting position from locking position, which is the single spare journey of the circuit breaker. By using the three path voltage sensors, one public force sensor and one public optical encoder of the instrument, the instrument can complete the switching synchronization of the three-circuit breaker when pushing.
(2)The switching-off process: When the switching-on process is over, a negative, linear, uniform moving and driving force to pull for the circuit breaker is provided like as the switching-on process. Then, a voltage pulse signal can be also measured when the circuit breaker switches off; the starting time can be got by using a clock in the computer during every path switching off; the pull force is measured, the dynamic changing curve of the force, the switching-off force and the unlocking force during switching-off process is acquired with same components as the switching-on process. When the force changing curve is up to the setting threshold, the circuit breaker is regarded unlocked and every path unlocking time is got by using the clock. Subtracting starting time from unlocking time, it is the single spare unlocking time of the circuit breaker. By using the three path voltage sensors, one public force sensor and one public clock of the instrument, the instrument can complete the switching synchronization of the three-circuit breaker when pulling. Fig.1 is measuring theory during switching on an industrial circuit breaker.

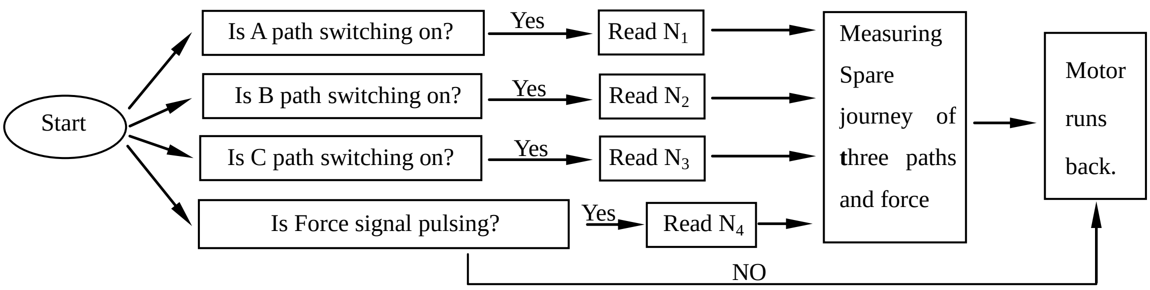

Fig.1 measuring theory (N_1、N_2, N_3 and N_4)

4 The whole design of the instrument

The measuring instrument is mainly composing of an industrial computer, a servo motor, a precision linear module, a force sensor, a high speed DAQ, measuring and controlling circuits and special clamp etc. By using LabView programming language, the automatic measuring and controlling software are programmed. In measuring, a series of controlling frequency pulse are transmitted to the servo motor to control it turning by using one port of the PCI-6143 DAQ card in the industrial computer, which drives a work-table on the precision linear module moving. The force sensor on the moving table, which connects to a breaker measured with a testing column, can provide a driving power to the breaker to simulate its working state. Then, the sensor measures the mechanical parameters and force-changing characteristic during the table moving. At the same time, the optical encoder of the servo motor can output corresponding frequency pulses to count the turning angle. The industrial computer reads pulse counts from a counter of the PCI-6143 DAQ card and the software system can figure out the actual moving distance according to unit displacement of every pulse represented.

If the optical encoder output is $N = 2500$ PPR and a displacement of the precision linear module is $m = 5mm$, the unit displacement of every pulse is

$$k = \frac{m}{N} = \frac{5mm}{2500} = 2\mu m$$

If the counter reads pulse counts is Q, the moving displacement of servo motor is

$$L = Q \times k = kQ$$

Fig.2 is measuring process. When the instrument works, the servo motor runs and drives the table moving forward. The industrial computer controls DAQ card acquiring the output signal of the force sensor which indicates the load of the circuit breaker. At the same time, the counter of the DAQ card starts counting the output pulse of the optical encoder. When the software system detects switching on of any path in the three-circuit breaker, the first output pulse count N_1 is recorded. Likewise, N_2, N_3 are recorded. When the circuit breaker locks up, the software system detects the output pulse of the force sensor, then, the industrial computer stops transmitting pulse to the servo system and the servo motor stops running, the moving table stops moving forward. Now, the forth outputting pulse count N_4 is recorded. Well then, the software system can figure out every path's spare journey of the three-circuit breaker. The instrument accomplishes automation measurement of the mechanical parameters and gets switching working state curve, switching force value, switching force changing process curve and switching synchronization of the three-circuit breaker.

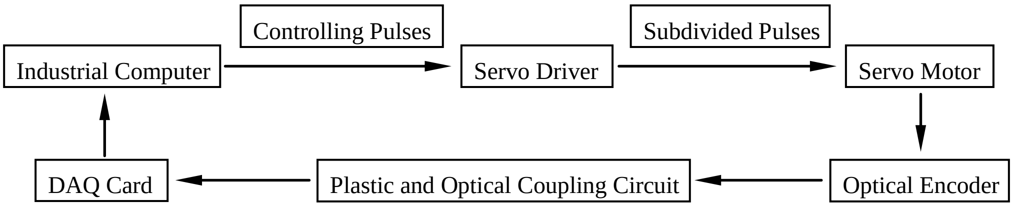

Fig.2 Measuring Process

The first path spare journey is

$$H_1 = (N_4 - N_1) \times k = k(N_4 - N_1)$$

The second path spare journey is

$$H_2 = (N_4 - N_2) \times k = k(N_4 - N_2)$$

The third path spare journey is

$$H_3 = (N_4 - N_3) \times k = k(N_4 - N_3)$$

Fig.3 instrument practicality

The switching-off measuring process is like the switching-on measuring process. What is different that time replaces the displacement as measuring parameter. Fig.3 is the instrument practicality.

5 Software design of the instrument

The instrument uses a virtual instrument technology - LabView software environment to design the whole software system of the instrument.

Fig.4 is the operation GUI of the instrument software. The man-machine GUI mainly includes menu function, dynamic curve display, switch control, real time database and servo-motor control display and so on. Fig.5 is the brief diagram block of control program in the software, which uses the synchronization control technology of LabView and using "Information Notification" technology carries on synchronization control and communication. In the software, "the master control task" takes as master thread. "The data acquisition and the synchronous detection task", "the electrical machinery control task" and "the database task" takes as the parallel three son threads. These parallel son threads are controlled by the master control task through the Notification technology, whenever, besides the master control task, only one of the three son threads is carried out and others are hanged up. When we click on "DATABASE" key in the operation GUI on fig.4, "the database task" son thread is activated and the program enters the database. This time, "the master control task" and "the database task" are synchronously executed, but the other two son threads both are hanged up.

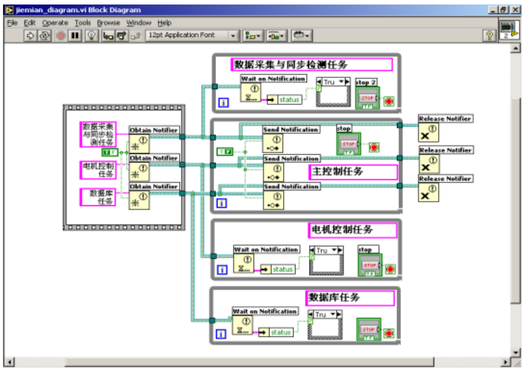

Fig.4 the operation GUI

Fig.5 the brief diagram block of the control program

6 The data acquisition and the synchronous measurement task

The son thread "the data acquisition and the synchronous detection task" of the software system is a measuring core. If the program enters the son thread, the measurement will be automatically done; the program will renew the dynamic curve in the GUI simultaneously. The instrument will display the final measurement result, and will automatically preserves parameters measured to the database finally.

The key problem of the data acquisition and synchronous measurement task is estimation about the end point of a switch-on process or switch-off process. The program counts to the feedback pulses of the servo-motor in the both end points, then, computes the spare journey of the switch-on process. Through the data index in the circulation measurement, the program computes the time-difference of the switch-off process. Finally, to find switching extreme forces in the switch-on process and the switch-off processes.

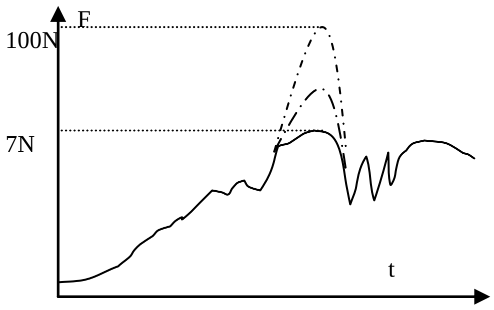

Fig.6 dynamic curve of force of switch-on process

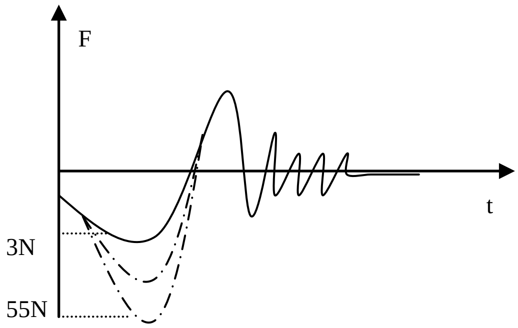

Fig.7 dynamic curve of force of switch-off process

Fig.6 and fig.7 are the signal of the force sensor in the switch-on process and switch-off process displayed on an oscilloscope respectively. When we push or pull the mechanical contact terminal of a circuit breaker to shrink or spring with connecting the force sensor, we can use the oscilloscope to watch the output signal of the force sensor. After the force value passes through the first big crest and trough, the switch-on process is completed, like fig.6. After the force value passes through the first trough, the switch-off process is completed, like fig.7. The variety of force crests about some other kinds of circuit breakers also are lined out in the fig.

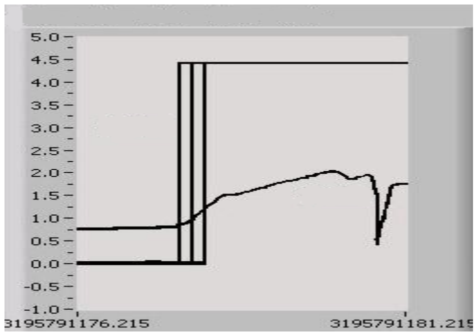

Fig.8 partial graph in switch-on process with the device

Fig.8 shows the dynamic curves of a three-circuit breaker in switch-on process. The three path voltages and the force signal are lined out. In order to accurately find the end point of the switch-on processes, we have designed two examination methods, that are force threshold value detecting and force wave crest detecting. The force threshold value detecting namely measures the force value after through the trough like fig.7. There are different force values to different breakers, sometimes, even if the similar circuit breakers can also have a bigger difference. The method of the force threshold value detecting depends on the experience, which sometimes is disabled. Therefore, we have designed another method of the force wave crest detection, which namely measures a force crest after crossed the trough like fig.8. The method only is acted as a supplement for the force threshold value detection. When the method of force threshold value detection is disabled, the force wave crest detection can accurately find the end point of switch-on process.

7 Servo motor control task

The servo motor control task mainly displays servo motor current movement status, with which may calibrate the entire system displacement precision, like Fig.9.

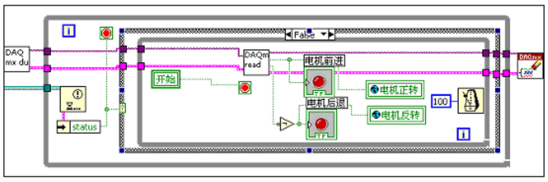

Fig.9 diagram block of servo-motor control task

The NI data acquisition card transmits a series of controlling frequency pulse to the servo motor, the pulse frequency is about 1KHZ. In order to prevent the emergency to the circuit breaker measured, user may urgently stop the servo-motor movement with the key of "stops" in the GUI of the instrument besides the software system. When the servo motor moves, regardless of goes forward or back, corresponding indicating lamp will be high light.

8 Testing about displacement precision of the instrument

The whole control driving system is constructed by the servo-motor and the precision linear module. Although several parts precision of the system are very high, the displacement precision also relies on the feedback pulses of the photoelectric encoder. The displacement precision to the spare journey in the switch-on process is asked above 10μm, which is mainly decided by an unit displacement value of a single pulse from the photoelectric encoder of servo-motor. In the system, the displacement is computed by counting the pulses of the photoelectric encoder. The servo-motor receives 10,000 pulses to run a circuit, while, the photoelectric encoder outputs 2500 pulses, and driving precision linear module goes forward 5mm. The ideal unit displacement value is K=5mm/2500=2μm for a corresponding single pulse.

We account the unit displacement value being 2 μm, in fact, the actual value needs to be calibrated. The pulses are received and read on time and accurately, therefore, the displacement precision of the whole system can be calibrated through an accessional standard instrumentation. We use a dial indicator and a set of gauge block to calibrate the system displacement precision. Through the control keys “go forward” and “go back” on the GUI of the instrument, we read the display of the displacement in the GUI and read the indicating of the dial indicator, which is regarded as a base. We compare each other. The above “K” is 2 μm, each time the actual displacement is S, the count value of the feedback pulse is N. Then, we may result in correction coefficient $\overline{K} = S / N$. Through the massive experiment data, fitting a correction line of the coefficient $\overline{K}$ using least squares method, we calculates $\overline{K}$ value:

$$\overline{K} = 1.970634$$

Substituting for 2 μm with the correction coefficient value $\overline{K}$ and utilizing the calibrate environment, we examine the whole displacement precision of the instrument. We carry on the statistics to the massive examinations data. The induction result is showed in table.1.

Table.1 positioning precision

list	1	2	3	4	5	6	7	8	9	10	11	12
Gauge block/mm	1	2	5	10	15	20	25	30	35	40	45	50
Deviation/mm	-0.002	0	0.003	0.003	0	-0.002	0	0.011	-0.007	0.001	-0.005	-0.001

9 Measurement result analysis

Taking a type of three-circuit breaker as a sample, measurement is continuously done with the instrument. The result is showed in table 2.

Table 2 measurement repeatability

list	A path journey	B path journey	C path journey	Switch on force	Switch off force
1	1.25mm	1.29mm	1.34mm	40N	21N
2	1.23mm	1.28mm	1.30mm	40mm	21N
3	1.24mm	1.29mm	1.32mm	41mm	21N

No matter what chooses any path of the product as reference point, we compute switch-on displacement. If taking A path as reference point, then, B displacement deviation is 0.04 mm, the separation time is 17 μs; C is 0.09 mm and 35 μs, the force value and displacement value in the request scope.

10 Conclusions

The instrument can obtain the mechanical parameters of industrial circuit breakers accurately; can provide a real-time database query system, can record the result automatically, can also save the real-time dynamic curves in the GUI. The instrument can provide the enormous convenience for the research on the mechanical characteristics of industrial circuit breakers.

Acknowledgments

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