Process Online Monitoring on Cold Extrusion of Internal Thread in High-strength Steel

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In order to solve the problems of data collection, data storage, artificial neural networks, real-time display of images, real-time monitoring of current status and recurrence of historical data, online monitoring system of cold extrusion of internal thread process is designed by LabVIEW8.5. The time-domain analysis and time-frequency-domain analysis are carried out for the torque signal, temperature signal, vibration signal, acoustic emission signal and transmitted signal. The research shows that: this online monitoring system can forecast processing status accurately, raise real-time alarm to replace or re-install the thread forming tap, accordingly avoids effectively the wreckage of thread forming tap and the scrap of work pieces; the fault recognition rate reaches 97%. And the practical model of online monitoring system for cold extrusion of internal thread process can be used to monitor working process.

Keywords: Internal thread; Extrusion; Torque; Temperature; Online monitoring

1 Introduction

Cold extrusion net shape process of the internal thread becomes a development trend on the anti-fatigue process of the present aircrafts, high-speed trains. The advantage is to keep the cold work hardening status on the surface and subsurface of internal threads. This not only improves the strength and hardness of material, but also increases the fatigue life of internal threads. Traditional cold extrusion process is only suited to the processes on the nonferrous metals with low-intensity, good plasticity and the low carbon steel. However for the processes on the high-strength steel series used for crafts and high-speed trains, the high-strength steel not only has the higher strength, but also has the higher fracture toughness. But the sensibility on the notch is higher at the same time; stress concentration is easily introduced, and is sensitive to the hydrogen brittleness and stress corrosion. Thus, reasonable processes should be conducted to increase machining precision and surface quality in order to obtain higher fatigue resistance. At present, the researches on this filed are all in fledging period and exploration stage with less of relative achievements [1-6].

During the process of cold extrusion of internal thread, how to avoid the wear, damage and fracture of thread forming tap are the technical problems. Thus, there is vital practical significance to execute online monitoring and real-time alarm during the process of cold extrusion of internal thread. This paper solves a sequence of problems with own designed monitoring system by performing signal processing analysis of the torque, the temperature, vibration, transmitted signal, feature extraction and selection, pattern recognition and other areas, to lay the foundation for the development of cold extrusion of internal thread process[7-12].

This paper designs and produces the online monitoring system of cold extrusion of internal thread process. The virtual instrument technology with LabVIEW8.5 is used as platform to realize the functions of data collection, data storage, artificial neural networks, real-time display of images, real-time monitoring of current status and recurrence of historical data; based on the foundation of the time-domain analysis and time-frequency-domain analysis of the torque signal, temperature signal, vibration signal, acoustic emission signal and transmitted signal, multi-sensors data fusion technology with the collaboration of multiple sensors is used to improve the monitoring precision; this online monitoring system can forecast processing status accurately, raise real-time alarm to replace or re-install the thread forming tap, and also avoids effectively the wreckage of thread forming tap and the scrap of work pieces.

2 Design and development of online monitoring system

2.1 Overall design of online monitoring system

During the process of cold extrusion of high strength internal thread, the changes of process conditions, such as lubricants, spindle speed of machine, diameter of underport of work pieces, extrusion times, have significant influence on the wear, damage, fracture of thread forming tap and the processing quality of work pieces; the measurement of torque, temperature, vibration and sound signals will provide reliable test parameters for the experimental studies. Thus, based on the features of online testing, online monitoring system is designed, and the torque, temperature, vibration and sound are characteristic parameters. Structure diagram of online monitoring system is shown in fig. 1: the system is consisted of sensors, signal modulation circuit, data acquisition card and computer. The physical parameters such as torque, temperature, vibration and sound during the working process are transformed into analog voltage signals via the sensors, the signals are magnified, filtered and transformed into digital signals; then they are input into computer via

the data acquisition card and the data is displayed, processed and stored.

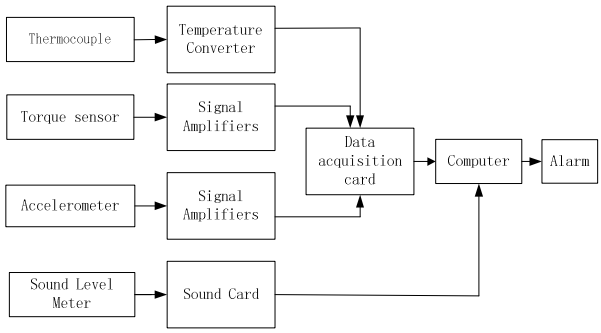


Fig. 1 *Structure diagram of basic system composing*

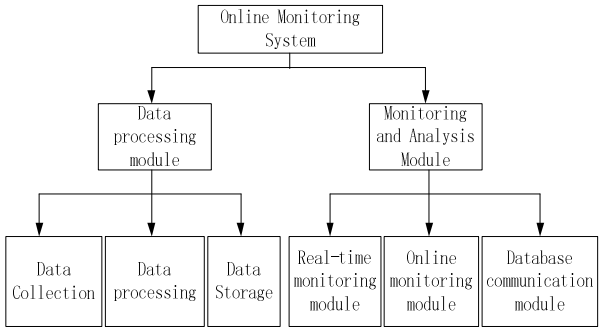


Fig. 2 *Schematic diagram of online monitoring system*

2.2 Realization method of hardware for the online monitoring system

Torque introduced during the process of cold extrusion of internal thread is measured by using the hollow circular shaft type of torque sensor. Resistance strain sensing element is adopted on the torque sensor, and the sensor is consisted of elastic shaft, measurement bridge, instrumentation amplifier and interface circuit. The elastic shaft is auxiliary elastic component; this not only increases the sensitivity of the tangential extrusion torque sensor and also reduces the interference between each other. BF-350HA (23) foil gauge is used as the bridge strain gauge, the normal resistance is 350 Ω, and sensitivity coefficient is 2.0; four electric resistance strain gages, which are 45° angle with the axis, are attached on the elastic shaft with 90° angle internal.

It is difficult to measure directly the temperature of the extrusion area in case that the deformation area is on the surface of internal bore of the work pieces during the molding phase of internal thread extrusion. Thus, the average temperature of extrusion area is measured after the work pieces are drilled. K type thermocouple is inserted into the hole of work piece in advanced, and fix it on the three-jaw chuck directly, both positive and negative electrodes of the thermocouple are lead out and connected with XMT-3000 industrial controler/regulator via the current collecting equipment at the foot section of the lathe spindle; the measuring precision is stable, measuring error introduced by temperature excursion and time drift are eliminated, and it has strong anti-jamming ability. In the thermocouple input mode, cold end compensating unit is equipped inside the instrument, and also volatge out port is equipped; temperature measured by thermocouple can be obtained after conversion.

TS152000 piezoelectricity acceleration sensor and TS6100 constant current optimal modulator are used to measure the vibration signals during the working process. During the measurement, the piezoelectricity acceleration sensor should be installed at the top point in the front of the clamping torque device, signal from the sensor during the working process will directly be input in the data acquisition channel of the data acquisition card via the current optimal modulator; correction factor should be determined during the measurement and calculation, and input into the stochastic signal and vibration analysis system software, then the vibration acceleration value of the measuring point will be output via the computer.

AWA5661 type impulse precision sound level meter is used to measure the sound signals during the working process; during the measurement, the sound level meter should be fixed on the board of machine tool, signal from the sensor will directly be input in the data acquisition channel of the data acquisition card, then the instantaneous sound level will be output via the computer.

2.3 Realization method of hardware for the online monitoring system

Online monitoring system is an integrated system with monitoring and prediction functions based on database. The database composition is shown in fig. 2; it is separated as two parts: cutting tool information database and working process information database. The cutting tool information database mainly includes the serial number of processing tap, using times, etc. The working process database mainly includes the process status of the cold extrusion of internal thread in different process conditions and the corresponding processed quality of work pieces.

In fig. 2, the online monitoring system mainly includes the data processing module and detection analysis module. The main functions of the data processing module are data collection, data processing, and data storage, etc. The detection analysis module is mainly consisted of real time monitoring module, online monitoring module and database communication module. The real time monitoring module mainly analyzes and judges the stability of process status via the real time monitoring of the torque and temperature during the working process, the module can raise early warnings in the serious situations, like work piece slipping, tap broken, ect, to fulfill the purpose of machine prevention. The online monitoring module is to judge and foresee the wearing status of cutting tools via the comprehensive analysis of the torque, temperature, vibration and sound signals in the previous process after this process is finished. This can provide feasibility prediction if the following process can be continued. The main functions of database communication module is to update the information of the thread forming tap timely after the working process is finished, and to update and supplement the working process information database if necessary. This can obtain better predictive effect[4-5].

Online monitoring system of working process is controlled by system software designed by LabVIEW8.5, the

front panel of the test system is shown in fig. 3, and it is consisted of four parts: real time display of images, instantaneous display of status parameters, status monitoring indication and the thread forming tap information display.

3 Selection and extraction of feature vector

The cold extrusion of internal thread process is a complicated flowing and forming process of metal. In this process, the extrusion torque, average temperature of the extrusion area, vibration of the tap and sound signals of the working process are all changing along with the different working process, but the signal information obtained from the sensor cannot be monitored directly. Due to the amount of the sensor signals is large while the information is quite few, it is difficult to establish the deterministic relationship with the changes of the cold extrusion of internal thread process. Thus the signals must be transformed accordingly to extract the signal features that reflect the changes of working process. This paper uses the multi-sensors data fusion technology to analyze the working process status under different process conditions. This can ensure the cold extrusion of internal thread process in smooth progress, as shown in fig. 4.

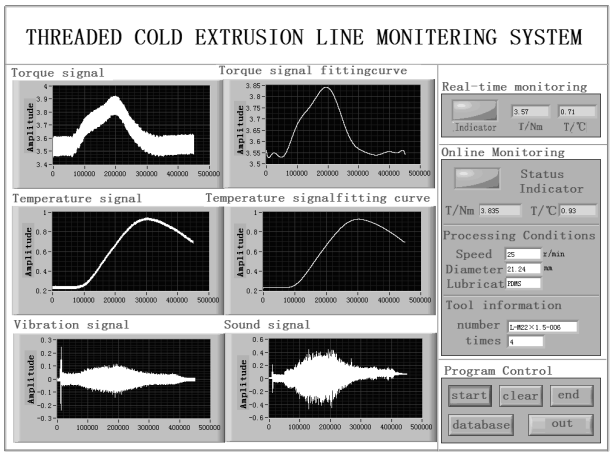


Fig. 3 *Front panel of the test systém*

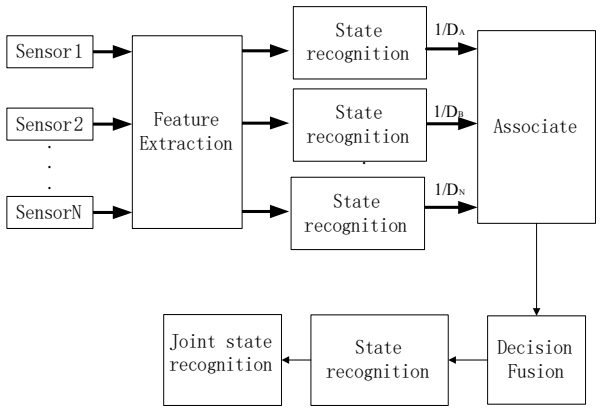


Fig. 4 *Decision fusion of sensor data*

The monitoring feature of the process changes for cold extrusion of internal thread process is obtained from the time domain and time-frequency domain signals analysis method. The data signals collected during the cold extrusion of internal thread process are classified based on different handling requirements. The extrusion torque and average temperature of extrusion area as changing curve are displayed, and time domain is analyzed and handled. The time domain feature such as the vibration of tap and working process sound should be considered, and the frequency variation law also should be considered, so comprehensive analysis of time domain and time-frequency domain should be conducted for the signals.

3.1 Signal features of the torque and temperature

During the cold extrusion of internal thread process, the signal of torque and temperature will be more or less impacted by the external factors. During the actual test process, the 50Hz electric supply is the main interference source against the extrusion process signal, and its signal is approximate sinusoidal wave. Least squares curve fit is used to remove the signal interference effectively; the least squares curve fit method is the fitting of a polynomial to minimum the quadratic sum of error, to find out a curve that make the most approach with all data points under the rule of minimum quadratic sum of error.

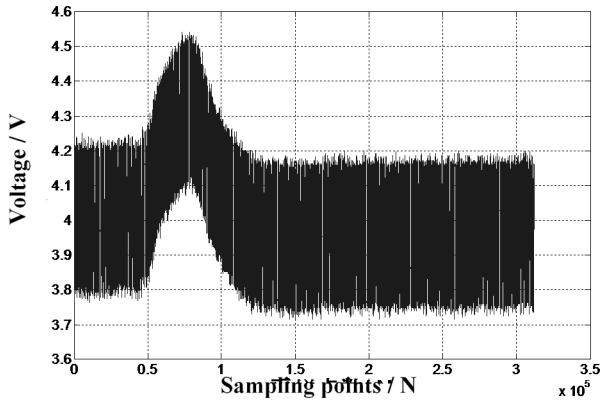


Fig. 5 *Time domain waveform figure of the torque original signals*

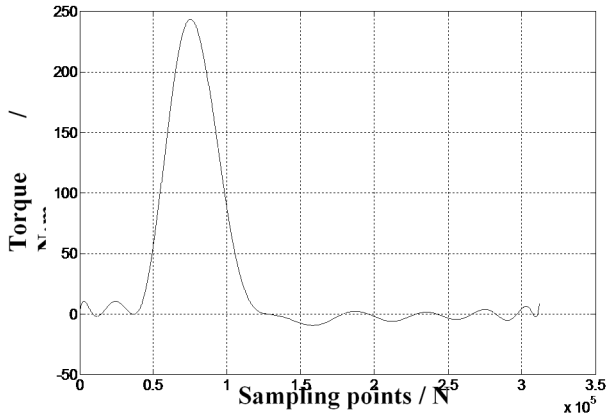


Fig. 6 *Torque during cold extrusion of the internal thread process*

Those selected signal samples are high strength steel Q460 under the working process, machine rotate speed is 25r/min and the length of thread is 20mm; the extrusion taps are lubricated by PDMS lubrication, the diameter d0

of bottom hole of the sample is Φ21.25mm. The fig. 5 shows the time domain waveform figure of the original signals, after the original torque signals are handled, the torque in the cold extrusion of internal thread process is obtained, shown in fig. 6. It can be seen that the torque increases along with the increase of the contacting area between the thread forming tap and the work pieces. Thus torque value can be extracted to be the monitoring feature to identify the working status of the cold extrusion of internal thread process.

The fig. 7 is the time domain waveform figure of temperature original signals during the cold extrusion of internal thread process, the relationship between the output voltage and actual collected temperature can be obtained based on the XMT0-3000 configuration, the temperature curve after de-noising processing is shown in fig. 8. The change of temperature is similar with the change of the torque, and both of them increase along with the increase of the contacting area between the thread forming tap and the work pieces. This reflects the concerned features during the working processes. Thus temperature value during the extrusion process can be extracted to be the monitoring feature to identify the working status of the cold extrusion of internal thread process.

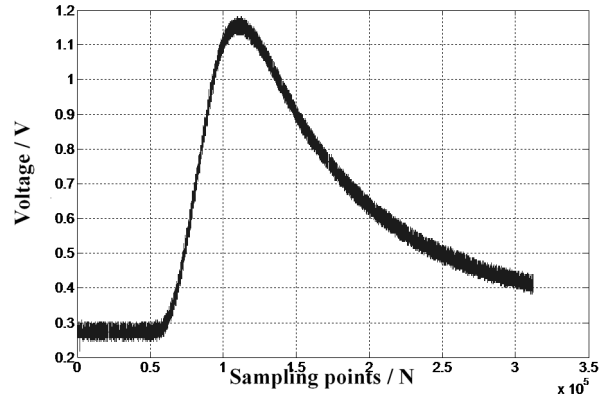


Fig. 7 *Time domain waveform figure of the temperature original signals*

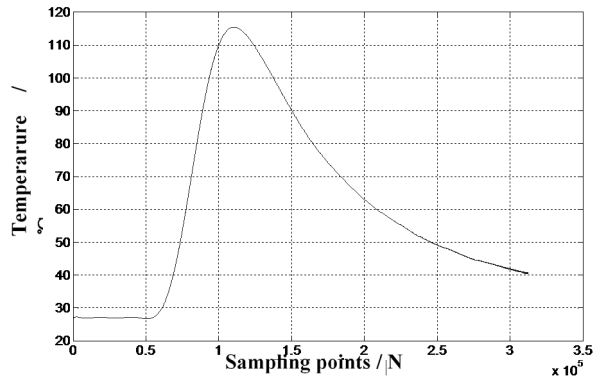
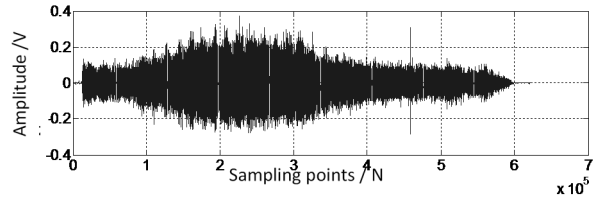


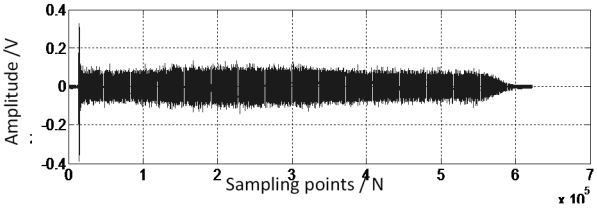
Fig. 8 *Temperature during the cold extrusion of internal thread process*

3.2 Signal features of the vibration and sound

The fig. 9 is the time domain waveform figure of vibration signals of thread forming tap and sound signals of machine tool during the cold extrusion of internal thread process, after the vibration and sound signals are handled, the autocorrelation function is shown in fig. 10. The vibration and sound signals are both stochastic signal during the working process.

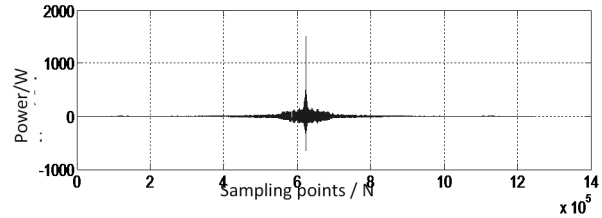


a) Vibration signals of thread forming tap

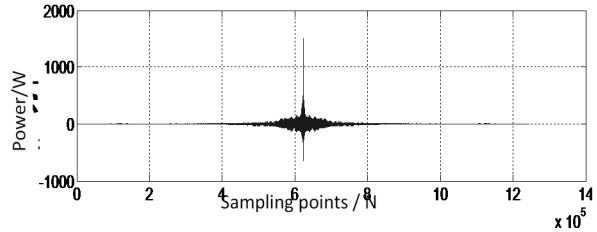


(b) Sound signals of the machine tool

Fig. 9 *Time domain waveform figure of vibration signals of thread forming tap and sound signals of macihne tools*



a) Vibration signals of thread forming tap

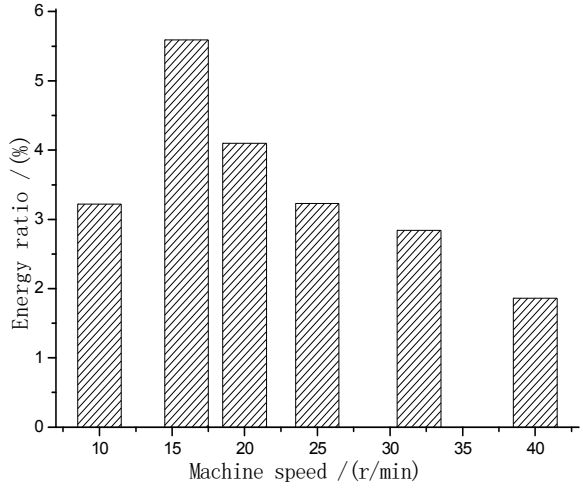


b) Sound signals of the machine tool

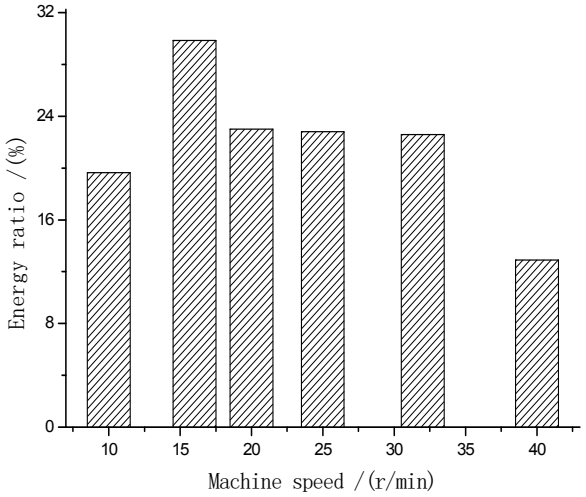
Fig. 10 *Autocorrelation function of vibration signals of thread forming tap and sound signals of macihne tool*

During the cold extrusion of internal thread process, the test results show that under the 5 kHz sampling frequency, the vibration signals of thread forming tap and sound signals of the machine tool are below 1500 Hz in the normal working situation; when abnormal situation, such as slipping, happens, the high-frequency section energy of signals will increase rapidly, thus the ratio of low and high-frequency section energy reflects effectively the status changes during the working process.

Fig. 11 is the energy ratio of vibration signals of thread forming tap and sound signals of the machine tool under different rotate speed of machine tool. Along with the increase of the rotate speed of machine tools, the energy ratio increases, then reduces. So it can be monitoring feature to identify the working status of the cold extrusion of internal thread process.



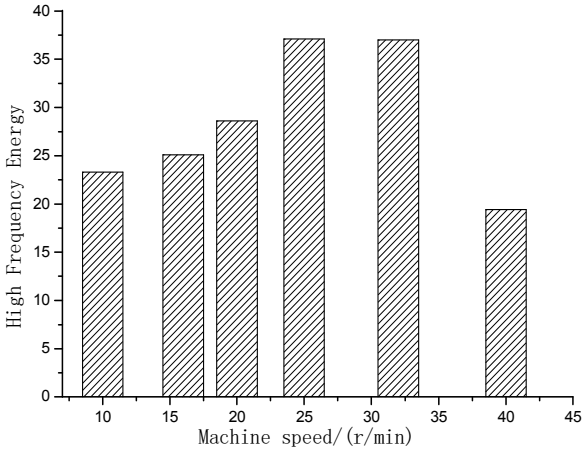
a) Vibration signals of thread forming tap



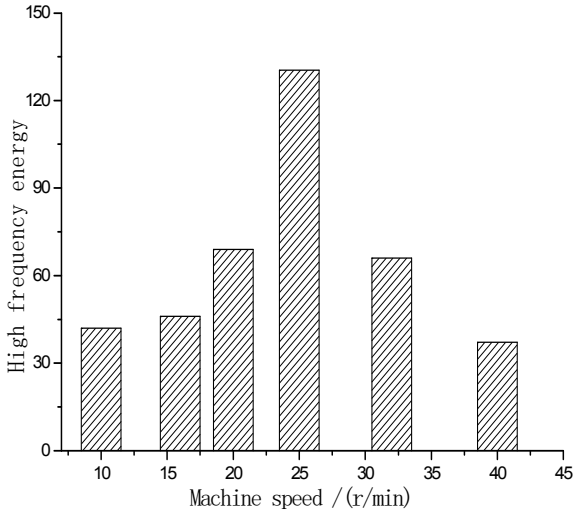
b) Sound signals of the machine tool

Fig. 11 *The energy ratio of vibration signals of thread forming tap and sound signals of the machine tool under different rotate speed of machine tool.*

Fig. 12 is the high frequency power of vibration signals of thread forming tap and sound signals of the machine tool under different rotate speed of machine tool. Along with the increase of the rotate speed of machine tools, the high frequency power increases, then reduces. So it also can be monitoring feature to identify the working status of the cold extrusion of internal thread process.



a) Vibration signals of thread forming tap



b) Sound signals of the machine tool

Fig. 12 *The high frequency power of vibration signals of thread forming tap and sound signals of the machine tool under different rotate speed of machine tool*

4 Analysis of monitoring results

Online monitoring test is conducted by using the monitoring system, the monitoring results analysis is shown in table 1, there are two thread forming taps damaged without any warning, only one thread forming tap is damaged seriously without any warning. There is no situation that the thread forming tap is slightly worn, damaged and slipping without any warning. The fault recognition rate reaches 97%.

Tab. 1 *Monitoring results analysis of thread forming tap worn*

Status of working process	Actual amount	Monitoring amount
Thread forming tap processed normally	10	10
Thread forming tap slightly worn	10	9
Thread forming tap seriously worn	10	8
Thread forming tap broken	10	10
Work pieces slipping	10	10

After the monitoring system is determined, system test is conducted by using process conditions of the online test. The cold extrusion of internal thread process is conducted on work pieces group by group; the real time changes of the working process are monitored. The test data from the online monitoring system is shown in table 2 to table 5. The wearing status of thread forming tap can be observed by microscope after machine is stopped. The wear mass loss can be determined by the difference value between the sum widths of all edge teeth before and after working process.

Tab. 2 *extrusion torque measure data of online monitoring system*

Processing Status	Extrusion torque (N·m)									
Normal processing	186	216	201	224	201	201	209	216	231	209
Taps mild wear	238	253	238	246	253	261	253	238	246	253
Taps severe wear	462	499	529	484	507	499	536	522	499	551
Taps fracture	894	1006	946	1082	944	1109	916	920	1047	1065
Workpiece slippage	656	678	700	678	715	683	742	779	693	701

Tab. 3 *extrusion temperature measure data of online monitoring system*

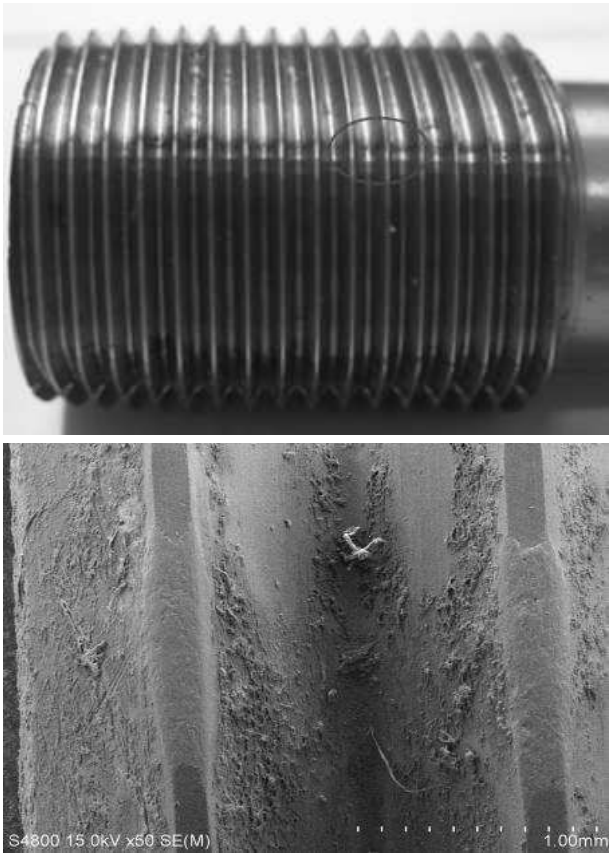
Processing Status	Extrusion temperature (°C)									
Normal processing	79	82	86	83	83	85	86	85	87	87
Taps mild wear	92	95	94	95	93	94	94	95	97	95
Taps severe wear	98	102	107	100	105	104	110	108	104	110
Taps fracture	147	152	138	145	149	144	138	142	144	148
Workpiece slippage	129	132	140	136	142	125	131	127	125	125

Tab. 4 *vibration measure data of thread forming tap of online monitoring system*

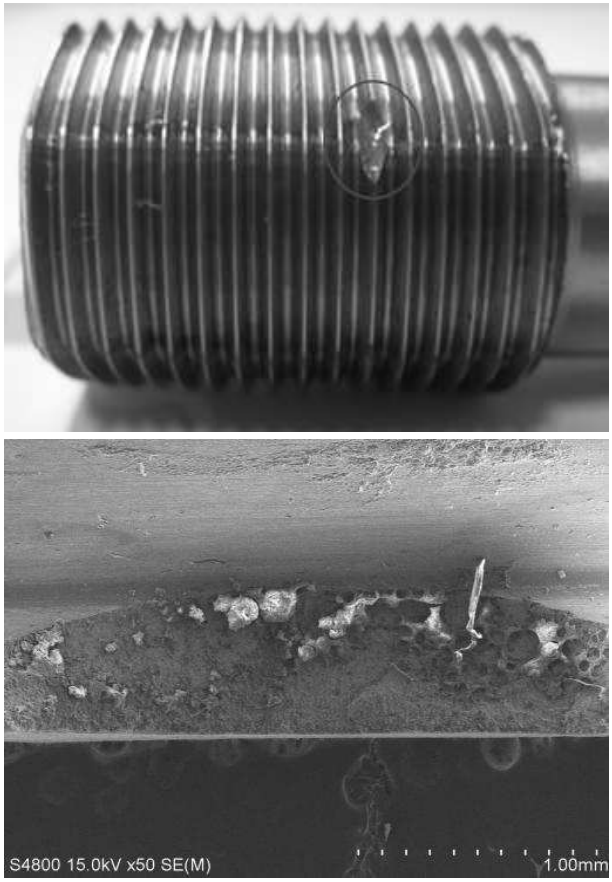
Processing Status	Extrusion tap vibration (total energy)									
Normal processing	178	175	180	182	175	185	184	182	180	178
Taps mild wear	195	197	200	203	198	207	189	210	205	201
Taps severe wear	225	223	215	220	217	228	219	221	223	231
Taps fracture	240	236	227	251	218	226	220	235	241	225
Workpiece slippage	208	210	205	215	207	213	205	210	212	214
Processing Status	**Extrusion tap vibrations (high frequency)**									
Normal processing	21.6	21.8	21.6	21.4	21.5	21.6	21.8	21.4	21.3	21.6
Taps mild wear	21.9	22	21.5	21.8	22.1	22.3	21.7	22.5	22.3	21.8
Taps severe wear	27.2	26.2	26.1	28.3	27.5	27.8	26.3	28.1	27.6	29.1
Taps fracture	27.2	24.3	22.5	29.1	26.4	25.5	26.2	24.8	26.1	23.6
Workpiece slippage	25.3	26	24.9	25.7	25.2	25.5	26.1	25.1	25.3	25.6

Tab. 5 *Online Monitoring System machine sound test data*

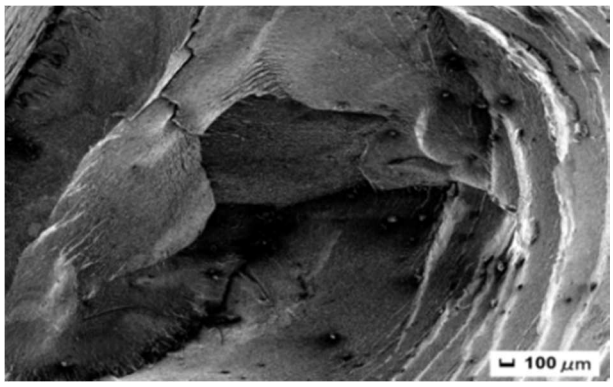
Processing Status	Sound Machine (total energy)									
Normal processing	1708	1658	1835	1927	1756	1870	1790	1823	1760	1523
Taps mild wear	1332	1503	1221	1642	1589	1613	1529	1460	1439	1620
Taps severe wear	12808	14927	15303	13498	11975	15630	11397	13450	17932	21057
Taps fracture	20793	25340	30561	31425	27431	26550	35460	23521	26590	24883
Workpiece slippage	33829	37980	40294	27650	35621	36435	29752	34267	41535	37611
Processing Status	**Sound Machine (energy ratio)**									
Normal processing	16	14.7	15	16.2	12.3	11.9	13.8	15.6	14.5	13.2
Taps mild wear	7.5	7.2	6.5	8.4	7.9	8.7	6.8	8	7.3	7.7
Taps severe wear	2.6	3.5	2.8	3	2.7	3.4	2.6	2.8	3.5	2.8
Taps fracture	2.2	3.4	2.5	2.3	2.4	2.4	2.7	3.3	3.5	2.1
Workpiece slippage	3	3.2	1.9	2.3	2.7	2.5	2.1	2.4	2.9	3.1



a) Slightly wearing status and partial enlarged drawing of thread forming tap



b) Seriously wearing status and partial enlarged drawing of thread forming tap



c) Broken status and partial enlarged drawing of thread forming tap

d) Slipping status of work pieces

***Fig. 13** photos and partial micrograms of thread forming tap under different working process status*

Fig. 13 shows separately the photos and partial micrograms of thread forming tap under wearing status, serious wearing status, broken status and slipping status.

5 Conclusion

Online monitoring system of cold extrusion of internal thread process is designed by the virtual instrument technology. LabVIEW8.5 is used as platform to realize the functions of data collection, data storage, artificial

neural networks, real-time display of images, real-time monitoring of current status and recurrence of historical data; based on the foundation of the time-domain analysis and time-frequency-domain analysis of the torque signal, temperature signal, vibration signal, acoustic emission signal and transmitted signal, multi-sensors data fusion technology with the collaboration of multiple sensors is used to improve the monitoring precision; this online monitoring system can forecast processing status accurately, raise real-time alarm to replace or re-install the thread forming tap, accordingly avoids effectively the wreckage of thread forming tap and the scrap of work pieces. Thus the practical model of online monitoring system for cold extrusion of internal thread process can be used to monitor working process, it is valuable to popularize to the industry.

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