

Study on Online Detection and Fault Diagnosis of Band Saw Equipment

Guojin Chen^a, Miaofen Zhu^b, Jing Ni, Huipeng Chen and Ming Xu

Hangzhou Dianzi University, Hangzhou, 310018, China

^achenguojin@163.com, ^bCorresponding Author, cgj@hdu.edu.cn

Abstract

Aiming at the lower automation, accuracy and efficiency of the domestic band sawing machine, this paper studies the real-time detection technology based on the sawing load, and develops the digital control system of the constant power sawing with the micro-feed performance to improve the load imbalance of the band saw blades in the sawing process.

Keywords: *Band saw equipment, Online detection, Fault diagnosis, State recognition system, Deviation-correction control*

1. Introduction

Due to the size and material changes and the hard impurities of the cutting workpieces in the band sawing process, the load of the band saw blades changes greatly so as to easily break the blades. The load of the band saw blades in the cutting process is unbalanced so as to easily produce the deviation of the saw blade's cutting path, even seriously affect the accuracy of the sawing. On the occasion of the heavy cutting to some materials, the artificial cutting is time consuming and laborious, and the efficiency is low. So there is an urgent need to develop the automatic weighing and measuring device for the band sawing machine. At the same time, the CNC technology is widely used in the high-level band saw machine. So the online detection technology of the band saw equipment is an important foundation for the solution of the above problems and the application of the numerical control technology [1-4].

Aiming at the lower automation, accuracy and efficiency of the domestic band sawing machine, this paper studies the real-time detection technology based on the sawing load, and the control system of the constant power sawing. The real-time detection technology based on the micro-deviation of the band saw's trajectory and the deviation-correction control system are studied. The weight-detection technology based on the scan reconstruction of the surface profile size and the control system of the fixed weight are researched. That can improve the accuracy and efficiency of the band sawing machine and provide the foundation for the realization of the digital control of the band sawing machine.

The fault diagnosis for the band sawing machine at home supplies usually the alarm information and the alarm lamp output when the proximity switch or contact switch collects the information over the designated station [5]. The fairly advanced band sawing machine has the HMI display to supply the alarm information. Those are low in the automatic diagnosis. The high-level CNC band sawing machine has the complex structure, and influenced by many factors. If the failure in the processing state can be not timely and accurately diagnosed, the machine will not be able to protect the manufacturing quality and accuracy. It will cause the waste to increase, the productivity to decline, or even result in a significant loss of the machine scrap. That urgently needs to introduce the dynamic monitoring and control with the intelligent diagnostic technology. The abnormal recognition and intelligent maintenance

theory for the processing state are studied to implement the status display, the fault diagnosis, and the performance predictability for the high-level CNC band sawing machine. That forms the unification of the monitoring information, diagnostic conclusion and real-time control strategy to achieve the high-precision and high efficiency machining purpose. So the fault diagnosis technology for the band sawing machine is urgent and necessary [6-9].

Now the fault diagnosis development for the CNC band sawing machine is towards the following aspects:

(1) The intelligent fault diagnosis strategy based on the multi-sensor information fusion is studied. The multiple types of advanced sensors are installed in the high-level CNC band sawing machine to detect a variety of troubleshooting information dynamically and real-time.

(2) In order to meet the digital transformation and upgrade of the band sawing machine, the other types of mature fault diagnosis for the CNC machine tool are gradually introduced.

(3) In order to achieve the real-time decision-making and effectiveness, the research on the decision processing theory for the efficient multi-channel information has gradually become a hot spot. The fault diagnosis advances to the intelligent direction.

2. Composition and Working Principle of Band Saw Equipment

The band sawing machine is composed by the sawing base, the saw frame, the saw blade's guide part and the workpiece-clamping part, as shown in Figure 1. The saw frame is supported by the hydraulic feeding cylinder and the pillar, on which is mounted the driving and driven saw pulley. The band saw blade is wound on the driving and driven saw pulley, and is tensioned by the tensioning mechanism (hydraulic tensioning cylinder and slider). The workpiece-clamping part is responsible for gripping the sawing workpiece (clamping cylinder and clamping block). The band saw blade is driven by the driving saw pulley (frequency conversion motor and worm gear reducer). The sawing movement of the specific workpiece is driven by a hydraulic feeding cylinder.

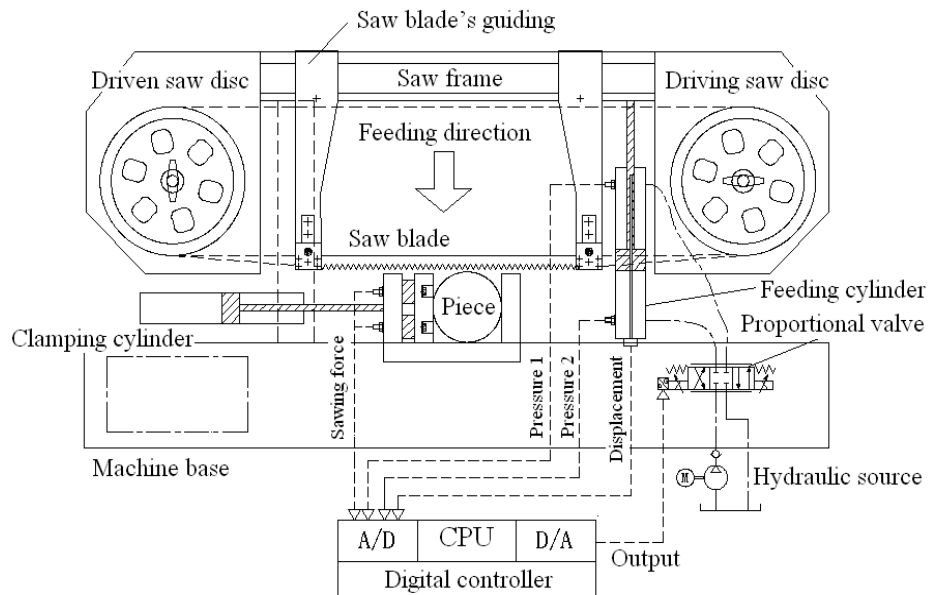


Figure 1. The Band Sawing Machine

3. Synchronization Drive Mechanism of Band Sawing Machine

The typical band saw equipment is shown in Figure 2. It is mainly composed of the portal frame, the driving and driven saw discs, the saw band, the correction device, the feeding hydraulic-cylinder, the cutting workpiece, the cutting table, the feeding guide column, the base, and the electrical control system. The sawing principle of the specific band saw equipment is: the band saw blades are wound on the driving and driven saws discs and the correction device. The correction device guarantees that the band saw blades are parallel with the workpiece's cutting surface. The spacing between the driving and driven discs is adjusted by the tensioning hydraulic-cylinder to tension the saw blades. The main movement is generated by the driving pulley (driven by the variable frequency motor). The feeding movement is generated by the feeding hydraulic-cylinder in the vertical direction. Furthermore, in Figure 1, T_M is the driven torque of the driving and driven saw discs. A, B, C, D are the tangent point's marking for the band saw blade and the band saw disc. O_1 , O_2 are the axle center's marking for the driving and driven saw discs. $T_0(s)$, $T_1(s)$, $T_2(s)$, $T_3(s)$ are respectively for the tensions suffered on the band saw at A, B, C, D. s is the coordinate variable of the arc length for the band saw blade, taking A as the origin. F_0 is the tensioning force for the band saw blade. Two feeding hydraulic-cylinders make up the synchronous drive mechanism for the band sawing machine.

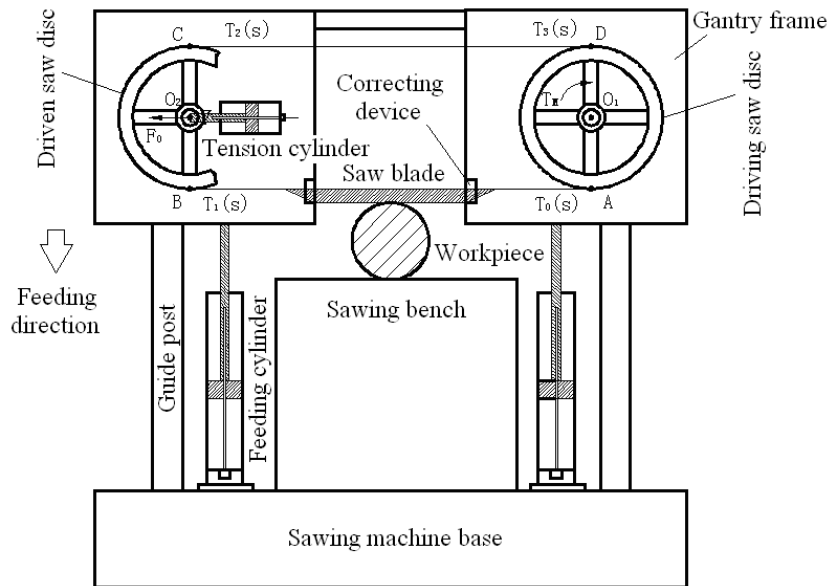


Figure 2. The Typical Band Saw Equipment

4. Electro-hydraulic Servo Synchronization Control Theory

As shown in Figure 3, the electro-hydraulic servo synchronization control system refers to the closed-loop electro-hydraulic servo mechanism composed by various proportional valves, servo valves or digital valves in order to achieve the movement synchronization of various hydraulic cylinders and hydraulic motors. Compared with the mechanical and hydraulic synchronization, although the composition of the control loop for the electro-hydraulic synchronization is more complex in structure and high in cost, the closed loop control made up by its output's detection and feedback can largely

eliminate and inhibit the adverse factors. That can obtain the high-precision synchronization driving performance [10-12].

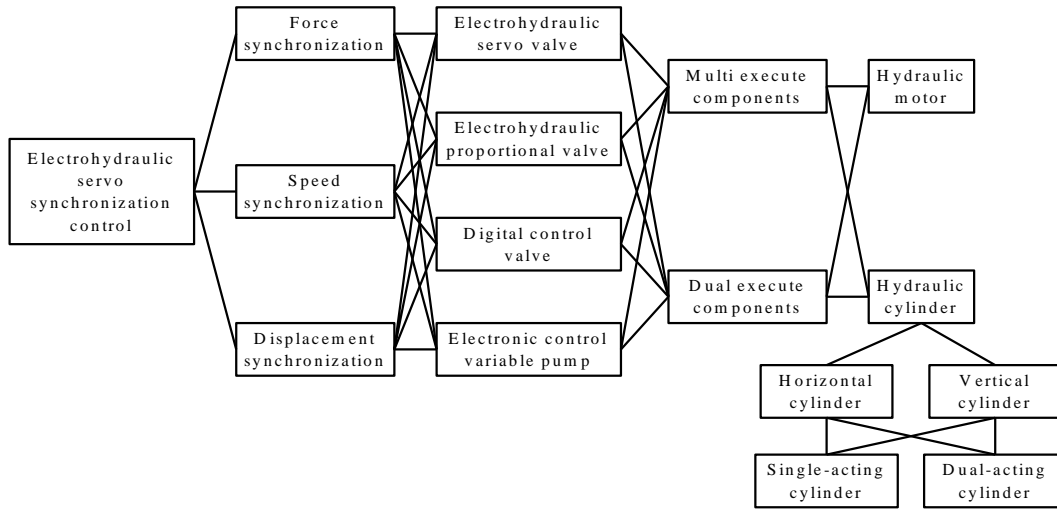


Figure 3. Electro-hydraulic Servo Synchronization Control System

So far the development of the foreign hydraulic synchronization driving technology has mainly three specific forms. They are the mechanical synchronization, the hydraulic synchronization based on the balancing valves and the electro-hydraulic servo synchronization. Hydraulic servo-driven synchronization control technology has high accuracy, flexible control, fast dynamic response, simple linear motion, as well as great power density. And with the increasing development of the control elements (mainly electro-hydraulic servo valve, electro-hydraulic proportional valve), the control means and methods continue to improve as well as the range of the computer applications continue to enlarge. It makes the servo system of the high accuracy and fast dynamic response to be little in the required the costs and risks. Therefore, the hydraulic servo-driven synchronization control technology can be applied in the accurate feed motion control of the band sawing machine.

However, because the nonlinear perturbation of and between its various channels is complicated and the hydraulic system itself has the complex nonlinear factors of the leakage, the dead zone, and the hysteresis, the system is difficult to detect and compensate real-timely. So the hydraulic servo-driven synchronization control technology has been the implementation difficulty of the electromechanical control.

5. Mathematical Model for Two-cylinder Electro-hydraulic Servo Synchronous Drive System

In order to establish the mathematical model of the two-cylinder electro-hydraulic servo synchronous drive system, without loss of generality, the load control problems for the two-cylinder horizontal-driver vehicle are considered, as shown in Figure 4. Setting $x=[x_1, x_2]^T$, we can get the mathematical model.

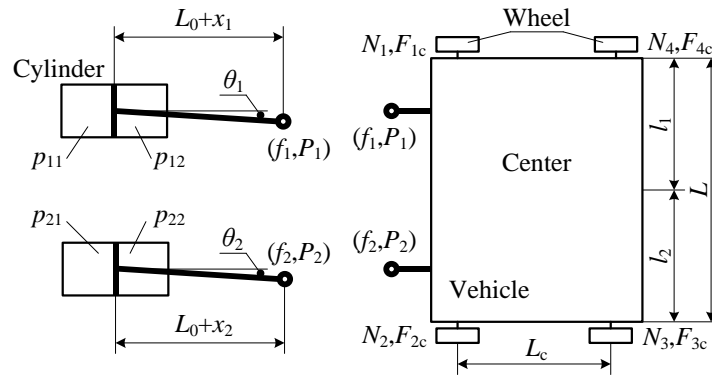


Figure 4. The Two-cylinder Electro-hydraulic Servo Synchronous Drive System

$$\begin{cases} M\ddot{x} + B_p\dot{x} = \tau \\ \dot{p}_{iL} = \beta_e K_{iq} \Psi_i(x_i, p_{iL}) \dot{x}_{iv} + \pi(x_i) p_{iL} + h_i(x_i) \dot{x}_i \end{cases} \quad i=1, 2$$

$$M = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} = \begin{pmatrix} m_1 + \frac{Ml_2^2 + J_0}{L^2} & \frac{Ml_1l_2 - J_0}{L^2} \\ \frac{Ml_1l_2 - J_0}{L^2} & m_2 + \frac{Ml_1^2 + J_0}{L^2} \end{pmatrix}$$

$$B_p = \text{diag} ([B_{1p} B_{2p}])$$

$$\tau = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} = \begin{bmatrix} A_{11} p_{1L} - F_{1c} - F_{4c} \\ A_{21} p_{2L} - F_{2c} - F_{3c} \end{bmatrix}$$

$$K_{iq} = C_d \omega_1$$

$$h(x_i) = \frac{\beta_e A_{i1}}{V_{ie}(x_i)}$$

$$\Psi(x_i) = \frac{1}{V_{ie}(x_i)} \sqrt{\frac{4(\alpha_{sv} p_s - \frac{x_{iv}}{|x_{iv}|} p_{iL})}{3\rho}}$$

$$\pi(x_i) = -\frac{C_{it} \beta_e}{V_{ie}(x_i)}$$

As the above formula, the two-cylinder electro-hydraulic synchronization and horizontal drive system has the cascade form of the linear system with the nonlinear system. Taking into account that the displacement feedback data collection for the hydraulic cylinders uses the magnetostrictive sensor of the high-frequency response, the response frequency greater than 1000 Hz, and much higher than the frequency of the system response, the sensor channel modeling can be approximated as a unit feedback link.

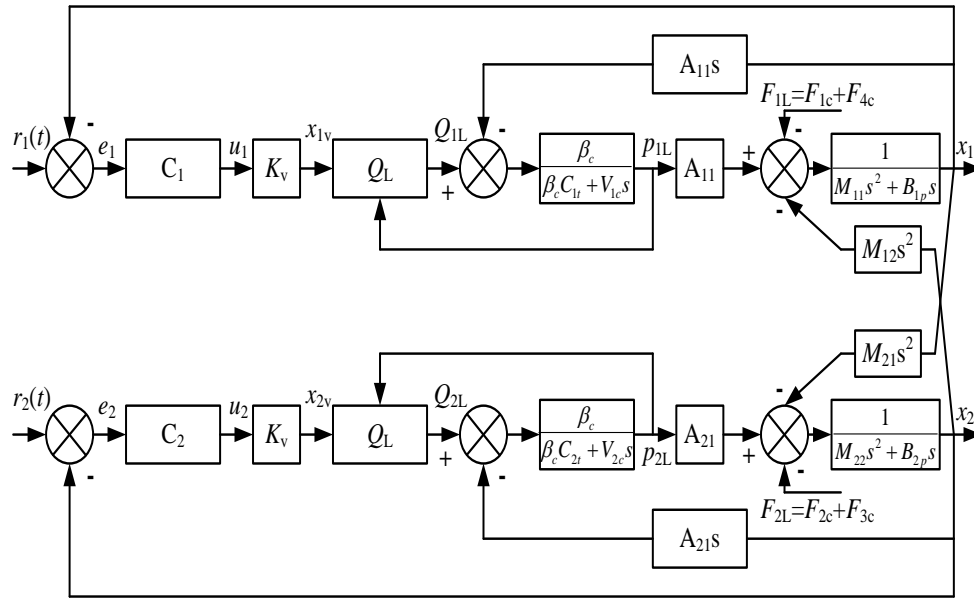


Figure 5. The Model of the Electro-hydraulic Servo System

So according to the above mathematical model, taking the conventional PID controller as an example, we can finally get the model of the electro-hydraulic servo system, as shown in Figure 5. r_1 and r_2 in the figure are respectively the desired control signal input channels.

6. Design for Electro-hydraulic Synchronization Servo Control System

First, according to the three forms of the current synchronous drive, the servo drive mode of the electro-hydraulic synchronization is used. The mode is that a valve controls a cylinder. Its specific driver is shown in Figure 6.

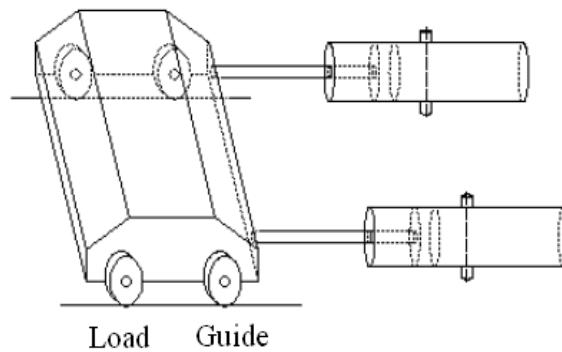


Figure 6. The Electro-hydraulic Synchronization Driver

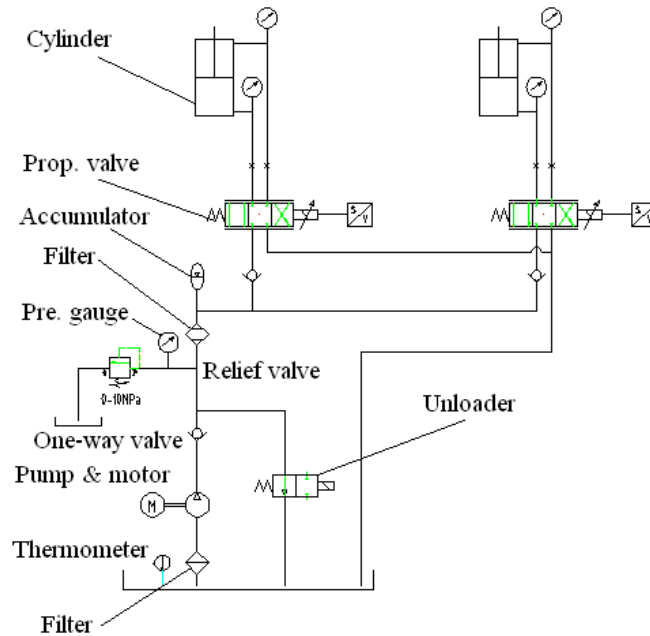


Figure 7. The Hydraulic System's Schematic Diagram

Second, the hydraulic system's schematic diagram is preliminarily design according to the actual performance of the band sawing process (stroke, running speed, cutting force, *etc.*), and the related critical components are selected, as shown in Figure 7.

Finally, the results of the preliminary design are verified and optimized in the key performance indicators to finalize the system design [13].

7. Design of Electro-hydraulic Servo Control System for Band Sawing Machine

In this paper, the synchronization drive mechanism of the gantry saw frame is designed using two guide posts to get the feed motion accuracy of the saw frame. The saw frame uses the structure which is driven synchronously by the dual hydraulic cylinders in order to guarantee the feed motion accuracy. The electro-hydraulic servo-driven synchronization control system detects the displacement feedback of the two cylinders, and uses the synchronous control strategy to achieve the movement synchronization of two gantry ends in order to ensure the movement accuracy of the gantry saw frame. The two-point feedback mechanism of the sawing force is set in the inlet and outlet of the band saw blade, and the two pressure sensors sample the load suffered by the band saw blade. The two-point feedback mechanism feedbacks the sawing force and controls the feeding speed of the synchronization system of the dual-cylinder electro-hydraulic servo-drive, so as to ensure the constant sawing load. That reduces the load fluctuation withstood on the band saw blade in the sawing process, thereby improves the saw blade's life of the band sawing machine. The schematic diagram of the control system is shown in Figure 8.

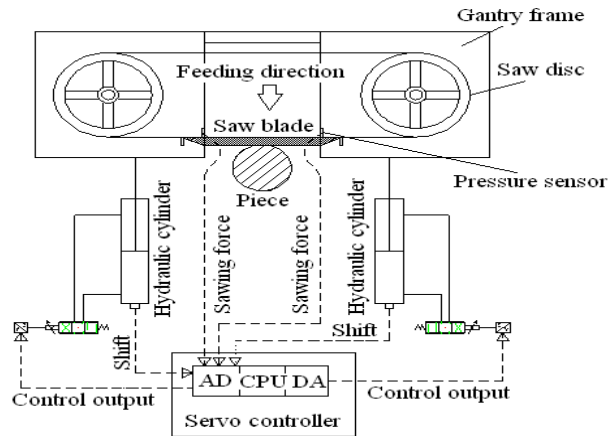


Figure 8. The Schematic Diagram of the Digital Control System

In order to verify the practical application effect for the control system of the band sawing machine, the control system designed in this paper is transplanted to the sawing prototype. The sawing parameters are optimized using the pre-established mathematical model on the sawing driven process. The actual sawing experiment and debug are done. The application of the electro-hydraulic servo control system in the large gantry CNC band sawing machine G42250 is shown in Figure 9.



Figure 9. The Large Gantry CNC Band Sawing Machine G42250

8. Real-time Detection Technology Based on the Transient Load Signal of the Band Saw

First, the reasons of the band saw load's transients and the bottleneck factors realizing the constant power sawing are analyzed. According to the observation and analysis of the actual sawing process, encountering the impure lumps of the workpiece or the sudden change of the cross-section in the sawing may be in an instant of centisecond. However, the centisecond may collapse the saw teeth. So the saw load detection of the high precision and high frequency response is the key of the constant power sawing. In addition, because the feeding rate of the band sawing is itself very small, about 0.1mm/min-2mm/min, the micro-feeding system of the high precision and high frequency response is required.

Then, according to the characteristics of the band saw's load transients and the described bottleneck factors of the constant power sawing, the digital control system of the constant power sawing is developed, as shown in Figure 1. The system uses the four-point pressure feedback unit of the clamping mechanism as the first judgment of the cutting load transients. The pressure feedback unit in the two chambers of the hydraulic feeding cylinder is taken as the second judgment of the sawing load transients. The electro-hydraulic servo-driven position system (proportional valve, hydraulic feeding cylinder, position sensor) is used to realize the micro-feeding control of the high frequency response. The digital controller with the A/D and D/A module is designed [14].

9. Real-time Detection Technology for the Micro-deviate of the Band Saw Trajectory

First, the deviating reasons of the band saw blades in the sawing process and the bottleneck factors on the automatic correction of the sawing trajectory are analyzed. According to the observation and analysis of the actual sawing process, the elongation of the sawing blade under the sawing tension, the uneven wear of the saw blade and the asymmetry on both sides of the saw blade may cause to lower the straightness of the sawing section (*i.e.*, the stiffness of the saw blade is worse). That leads to the sawing trajectory deviation of the band saw blades. So the deviation detection of the high precision and high frequency response to the band saw's trajectory is the key to achieve the automatic correction. In addition, due to the fast line speed of the band saw, about 10-100m/min, the automatic correction system of the band saw with the high precision and high frequency response is also required.

Then, according to the saw trajectory deviation features and the described bottleneck factors of the automatic correction, the digitized correction control system of the saw trajectory is developed, as shown in Figure 10. The system uses the two-point eddy current sensing unit to detect the saw blade's trajectory deviation. The electro-hydraulic servo-driven tensioning system (proportional overflow valve, shuttle valve and hydraulic tensioning cylinder) is used to achieve the saw tension control with the high-frequency response and the rigid adjustment of the saw blade so as to implement the automatic resetting of the saw trajectory. The digital controller with the A/D and D/A module is designed.

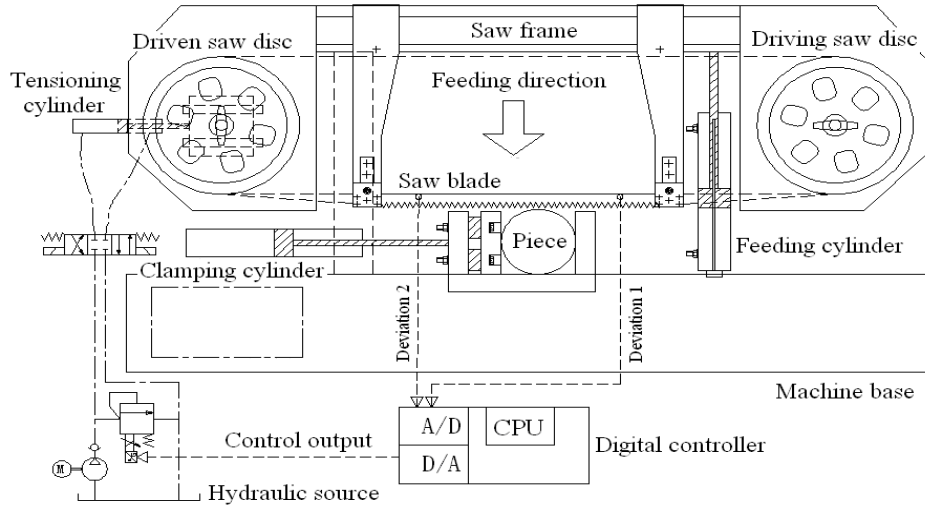


Figure 10. The Digitized Correction Control System of the Saw Trajectory

10. Weight Detection Technology Based on the Scan Reconstruction of the Surface Profile Size

First, the weighing principle of the workpiece's pre-intercepting part and the bottleneck factors to achieve the virtual weighing of the pre-intercepting part are analyzed. According to the observation and analysis of the actual sawing process, the existing two-dimensional scanning system is very expensive in the price, and relatively limited in the detection range is (less than 100mm in diameter). So the x-y axis driven dynamic scanning mode based on the one-dimensional laser ranging principle can establish the three-dimensional model of the pre-interception part to get the weight prediction. That is the key to achieve the virtual weighing. Further, since the detected speed is required to be faster, about 0-5s, the x-y axis driven dynamic scanning system with the high precision and high frequency response is needed.

Then, because the cross-sectional shape of the existing sawing workpiece is mostly the convex curve, the digital control system for the fixed weight sawing needs to be developed, as shown in Figure 11. The system uses two sets (Figure 11 gives only one) of scanning step-driven slides in the left and right sides to carry the one-dimensional laser range finder to move in the y direction. The step-driven feeding raceway is used to drive the workpiece. The digital controller with the A/D and D/A module is designed.

The three-dimensional virtual weighing process of the workpiece's pre-intercepting part is as follows. As shown in Figure 11 and 12, assuming that the spacing of the laser range finder in the right and left is L , the measured distance in the left rangefinder (the distance from the point A on the workpiece) is ly_1 , the measured distance in the right rangefinder (the distance from the point B on the workpiece) is ly_2 , then the distance ly_1 on both sides AB in the same height of the workpiece's cross-section can be obtained by the following formula.

$$ly = L - ly_1 - ly_2$$

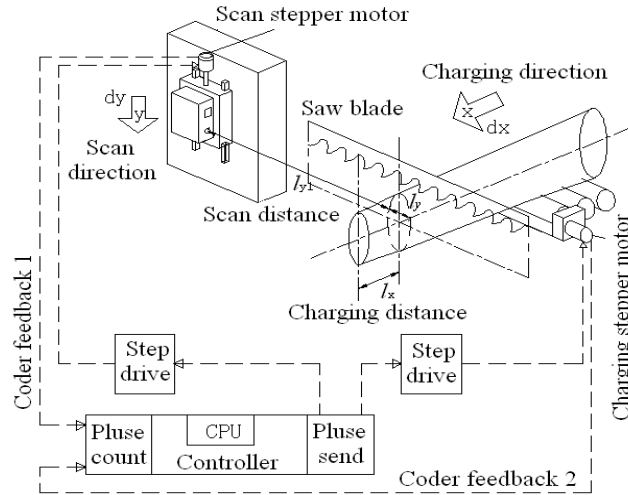


Figure 11. The Digital Control System for the Fixed Weight Sawing

Thus, the workpiece's cross-sectional area S can be obtained by the integral superposition of the small rectangle area in the y -axis direction. Specifically it can be represented as

$$S = \sum_{j=1}^m l_y dy$$

Wherein, m is the number of measurements in the y direction, dy is the feeding distance of the scanning step motor each time. Therefore, the weight G for the pre-interception part of the workpiece is

$$G = \rho \sum_{i=0}^n \sum_{j=1}^m l_y dy dx$$

Wherein, n is the number of measurements in the x -direction, dx is the feeding distance of the stepping motor each time, ρ is the workpiece's density.

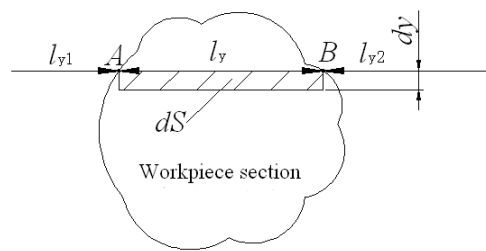


Figure 12. The Calculation of the Workpiece's Cross-sectional Area

11. Blade Life's Correlativity with Amplitude and Frequency Characteristics of Flutter Signal

First, the bottleneck factors of the saw-tooth life prediction are analyzed. According to the observation and analysis of the actual sawing process, the saw-tooth work status

(new, wear, cracks, broken teeth, *etc.*) and the amplitude-frequency characteristics of the saw-blade's flutter signal has a certain coupling relationship. However, the saw-blade's flutter signal has the larger external signal interference, such as the body vibration, the guide vibration and the vibration of the load changes. Therefore, extracting the flutter's amplitude-frequency characteristics which can reflect the saw-blade life's characteristics is a key to the identification system for the saw-blade's reliability.

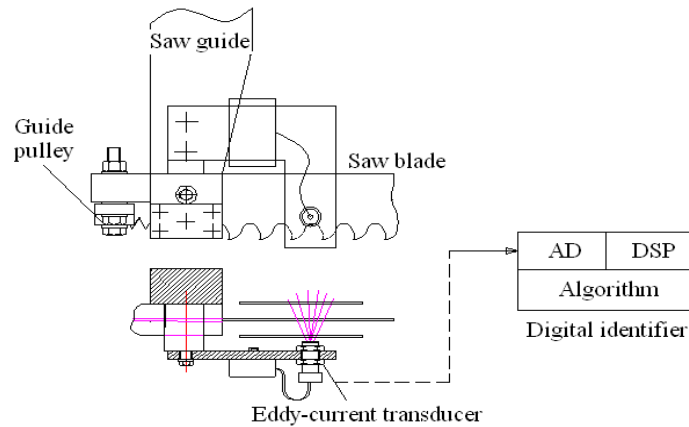


Figure 13. The Identification System for the Saw-blade's Reliability

Then, the identification system for the saw-blade's reliability is developed, as shown in Figure 13 and Figure 14. The current displacement sensor on the system's guide device detects real-timely the saw-blade flutter signal. The denoise method based on autocorrelation and cross-correlation is studied to eliminate the noise of the saw-blade's flutter signal. The wavelet basis narrowband spectrum analysis method is researched to extract the amplitude-frequency characteristics reflecting the saw-blade life, in order to obtain the blade life's correlativity with the amplitude-frequency characteristics of flutter signal. Using the above methods obtains the blade life's correlativity with the amplitude-frequency characteristics of flutter signal in the different use stages to establish the evaluation references. So you can design the digitized identifier with the blade life recognition feature.

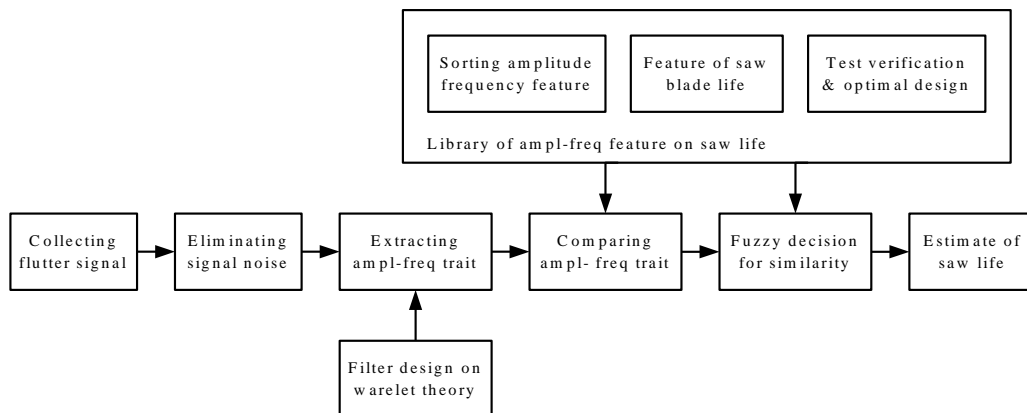


Figure 14. The Identification Principle for the Saw-blade's Reliability

12. Variation Law of Brush Friction with Inclination Angle Φ between Saw Blade and Brush Plate

First, the formation reasons of the sticky chips between the saw-blade teeth and the bottleneck factors to remove effectively the sticky chips are analyzed. According to the observation and analysis of the actual sawing process, the improper sawing parameters, the friction of the saw blade and the workpiece, the poor lubrication, the continuous work and the improper saw-blade shape can cause the sticky chips. The saw blade with the sticky chips may largely reduce the sawing accuracy and efficiency. So the efficient device removing the sticky chips is the key to improve the sawing reliability.

Then, according to the existing chip-removal program shown in Figure 15 (a) and the key factors for removing effectively the sticky chips, the chip-removal device of the rotary damper is developed, as shown in Figure 15 (b). On the device, the brush plate institution which can be locked in any rotary angle Φ is designed to regulate the friction between the saw-teeth and the brush (brush friction force). The variation law of the brush friction with the inclination angle Φ between the saw blade and the brush plate is studied. The brush disk's rotating mechanism is designed optimally. The magnetic transmission institution is designed to absorb the chips falling into the lubricating coolant tank and discharge automatically. The brush disk which has the specific wire diameter and the cluster spacing is designed to remove the sticky chips and absorb the lubricating fluid effectively for lubricating and cooling the saw-teeth.

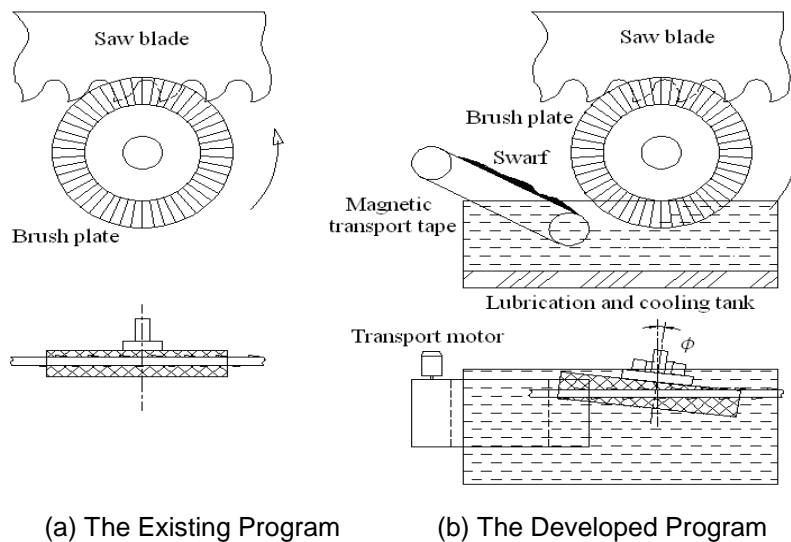


Figure 15. The Chip-removal Device of the Rotary Damper

13. Real-time Detection of Oil Temperature, Pressure, Flow Rate and Hydraulic-cylinder Displacement and Wireless Transmission Technology

First, the working principle of the hydraulic oil circuit and the bottleneck factors to implement the reliable feedback of the hydraulic circuit are analyzed, as shown in Figure 16. According to the observation and analysis of the actual sawing process, the existing hydraulic system has three problems. The first is to be unable to recognize the working state of the oil source. The second is to be unable to identify the working state of the clamping, feeding and tensioning hydraulic-cylinders online. The third is the

compact body of the band sawing machine which brings the greater difficulties for the detecting and feedback wiring of the hydraulic system. Therefore, using the wireless transmission principle, to develop the feedback device of the key actuator for the pressure, flow and position is the key to achieve the real-time identification of the hydraulic system's state.

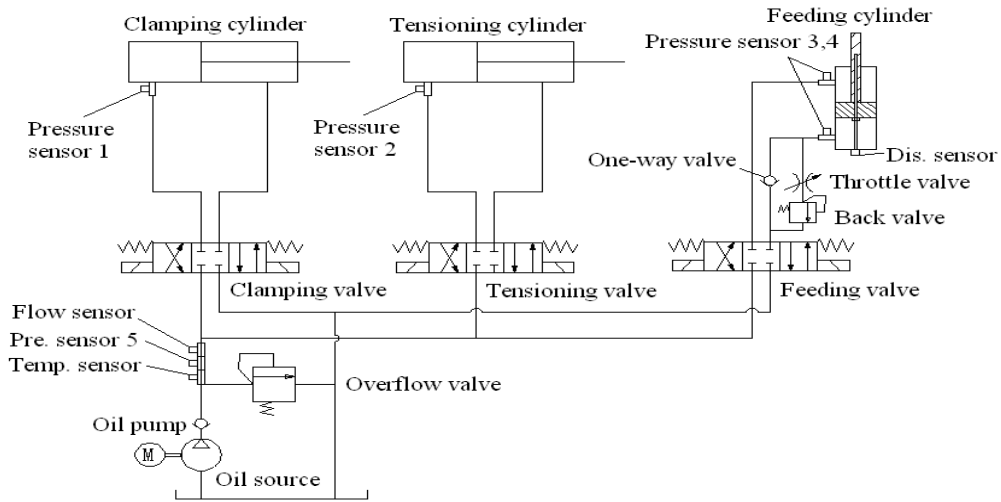


Figure 16. The Identification System of the Working State

Then, according to the working principle of the hydraulic circuit for the band sawing machine and the signal feedback analysis on the reliability, the identification system of the working state for the hydraulic oil system is developed using the wireless transmission type, as shown in Figure 16 and Figure 17. The system collects the pressure, flow rate and temperature signals of the key points in Figure 16 (the oil source supply, the clamping cylinder, the tensioning cylinder and the feeding cylinder), using the 8-channel 10-bit precision AD converter interface. The actual feeding displacement of the hydraulic cylinder is collected using the SSI interface. The identifier of the working state for the hydraulic circuit is designed with a wireless transceiver module.

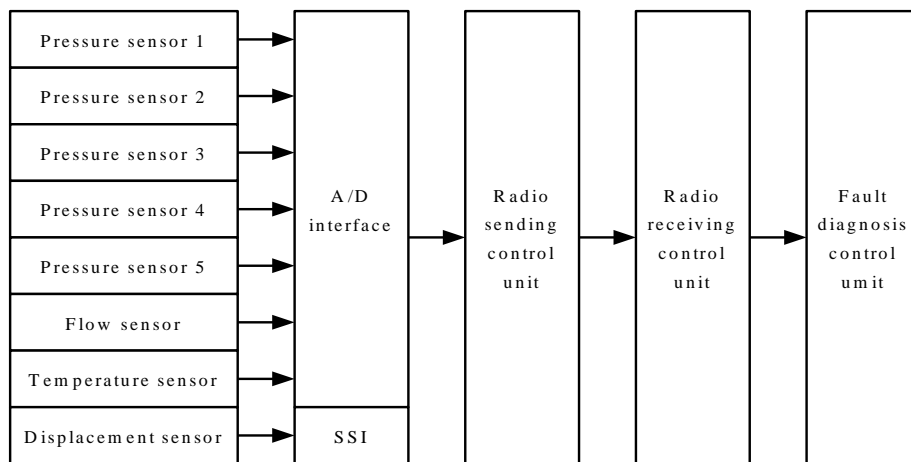


Figure 17. The System's Schematic Diagram Using the Wireless Transmission Type

14. Conclusion

(1) For the cutting process of the existing band saw equipment cannot perceive the sawing workpiece's impure lumps or the section's abrupt change, the momentary overload is easy to produce the abnormal damage of the band saw blades. The real-time detection technology of the load transient signal of the band saw in the cutting process is used. The digital control system of the constant power sawing with the micro-feed performance is developed to improve the load imbalance of the band saw blades in the sawing process. That can improve the life of the saw blade and the sawing reliability.

(2) For the existing band saw wears and the cutting edges on both sides are asymmetric, it is easy to produce the larger deviation of the cutting trajectory so as to affect the cutting surface quality. The real-time detection technology for the slightly deviation of the band saw's trajectory is used. The digitized correction control system of the saw's trajectory with the performance to fine-tune the stiffness is developed to automatically correct the band saw's trajectory. So the life of the saw blade and the cutting quality can be improved.

(3) For sawing the workpiece in the specified weight for the irregular distribution in the cross-section, the weight-detection technology based on the scan reconstruction of the surface profile size for the workpiece's pre-interception part is used. The digital control system of sawing in the specified weight is developed to realize the weight error of the sawed workpiece under 3%, thereby to improving the cutting efficiency and performance.

(4) For the existing band sawing equipment cannot perceive the cracks, wear and remaining life of the saw-blade teeth, the reliability identification system with the life prediction function for the band saw-blade is developed using the extraction technology for the flutter's amplitude-frequency characteristics which can reflect the saw-blade's life characteristics. So that can diagnose and predict the saw-blade's replacement online to reduce the risk occurrence of the broken tooth's splash, and improve the use reliability of the band sawing machine.

(5) For the existing band sawing machine can not clear the sticky chips on the saw-teeth and greatly affects the saw-teeth's life, the adjustable device which clears the sticky chips between the saw teeth is developed according to the brush friction change with the inclination angle Φ between the brush disk and the saw blade. That implements the effective removal of the sticky chips on the saw-teeth, thereby to improve the saw-blade service life and the sawing quality.

(6) For the existing band sawing machine can not perceive the hydraulic system's failures and reduces the whole reliability, the wireless identification system of the working state for the hydraulic oil system is developed using the real-time detection of oil temperature, pressure, flow rate and hydraulic-cylinder displacement and wireless transmission technology. That implements the real-time monitoring and fault diagnosis of the oil source, then improves the working reliability for the hydraulic system of the band sawing machine and reduces the machine's power consumption.

References

- [1] Z. Jie, C. Guo-jin and W. Wan-qiang, "Applying FPGA on Frequency Convert System of SVPWM", *Mechanical & Electrical Engineering Magazine*, vol. 22, no. 4, (2005), pp. 22–25.
- [2] C. Guo-jin, Y. Zhai-rong and S. Hong, "Realization of AC Motor Vector Control Based on DSP", *Mechanical & Electrical Engineering Magazine*, vol. 21, no. 6, (2004), pp. 27–30.
- [3] W. Tao, C. Guo-jin and N. Jing, "Design and application of electric control system on pattern drawing machine", *Journal of Mechanical & Electrical Engineering*, vol. 29, no. 4, (2012), pp. 413–416.

- [4] L. Yong-ning, Y. Hua and C. Guo-jin, "Application of $\mu\text{C}/\text{OS-II}$ in digital welder control system", *Journal of Mechanical & Electrical Engineering*, vol. 28, no. 7, (2011), pp. 827-830.
- [5] G. Chen, J. Ni, T. Liu, H. Chen and Ming Xu, "Study on Fault Diagnosis Technology for Band Sawing Machine", *Advanced Materials Research*, vol. 718-720, (2013), pp. 1160-1164.
- [6] C. Guo-jin, C. Hui-peng and C. Li-ping, "Research on multidisciplinary modeling and robust control for electric power steering system", *Advanced Materials Research*, vol. 179-180, (2011), pp. 179-185.
- [7] C. Guo-jin, D. Kai-ping and G. You-ping, "The Design and Simulation of Walking Hydraulic Transmission System of Loader HT25J", *Mechanical Engineer*, no. 6, (2012), pp. 46-49.
- [8] C. Guo-jin, L. Ting-ting, N. Jing, G. You-ping and F. Huo-qing, "Study on Control Characteristics of Driving and Lifting System for Logistics and Loading Machinery", *Applied Mechanics and Materials*, vol. 268-270, (2013), pp. 1517-1522.
- [9] G. You-ping, B. Xiang-juan and C. Guo-jin, "Excavator operator mechanism and hydraulic integration model construction and simulation based on modelica", *Applied Mechanics and Materials*, vol. 130-134, (2012), pp. 666-671.
- [10] X. Ming, N. Jing and C. Guo-jin, "Research on the Broaching-load Testing System of Hydraulic Broaching Machine", *Advanced Materials Research*, vol. 328-330, (2011), pp. 1709-1712.
- [11] G. Chen, J. Ni, T. Liu, M. Xu and H. Chen, "Research and Application for Two-cylinder Electro-hydraulic Servo Synchronous Control Technology", *Applied Mechanics and Materials*, vol. 344, (2013), pp. 139-144.
- [12] G. Chen, J. Ni, T. Liu, H. Chen and M. Xu, "Study on Material-cutting with Electro-hydraulic Servo Synchronization Control System for Large Band Saw Equipment", *Advanced Materials Research*, vol. 675, (2013), pp. 86-90.
- [13] G. Chen, J. Ni, T. Liu, H. Chen and Y. Gong, "Study on Optimizing the Process Parameters for the Band Saw Equipment", *Applied Mechanics and Materials*, vol. 328, (2013). Pp.208-212.
- [14] G. Chen, J. Ni, T. Liu, H. Chen and M. Xu, "Study on the Online Detection Technology of the Band Saw Equipment", *Advanced Materials Research*, vol. 753-755, (2013), pp. 2329-2333.