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Improving Reliability and Productivity of an Aluminum Extruder by Implementation of Direct Torque Control Technology

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Abstract: Problem statement: The linear motor drive is widely used in driving an extrusion puller in an aluminum extrusion industry. The main disadvantage of this drive is manual and step-wise torque control. This research was done to replace the linear motor drive by AC drive with direct torque control technology. **Approach:** Mathematical calculations were carried to select an AC drive which satisfied parameters and values required for production process. Motor rotational speed and torque were calculated from required linear velocity of puller machine and pulling force required for extruded aluminum sections. **Results:** The suggested AC drive with direct torque control was implemented and installed. It proved higher reliability due to elimination of mechanical problems and wears. Higher productivity was obtained due to flexibility and automation of speed and torque control modes. **Conclusion/Recommendations:** Implementation of AC drive with direct torque control led to savings in electrical energy consumption, reduction in breakdown and maintenance intervals and improvement of product quality. AC drive with direct torque control was suggested to replace other drive types in all industrial applications were torque and speed modes of control were required.

Key words: Extruder, extrusion puller, motor speed control, direct torque control, programmable controller

INTRODUCTION

Aluminum extruded profiles are used in manufacturing of building doors and windows as in many different industrial applications such as radiators and heat sinks. These profiles come with different dimensions, shapes and finish, as shown in Fig. 1. An extrusion process starts with a raw material, in form of long billets, preheated to required temperature and then transferred to the extrusion press to be extruded through die orifice into required form and dimensions, as shown in Fig. 2 and 3. The synchronization of the operation and control of these production machines is required to reach high level of productivity and quality of the finished product[1,2]. A considerable benefits at an extrusion plant has been involved by the modernization and improvement of the extrusion puller drive system. This operation involved replacement of a linear motor control system with a standard AC induction motor controlled by a high performance AC drive with Direct Torque Control Technology (DTC). The actual speed of the motor, the process speed, the frequency applied to the motor, the motor torque in per cent of the rated motor torque, the motor power in percent of rated motor power, the mains voltage and the motor voltage are calculated by the controller and can be monitored and displayed for operator. The motor current, the DC bus voltage and the temperature of the heat sink in degrees centigrade are measured by the controller and can be monitored and displayed also[8].

Fig. 1: Extruded aluminum profiles

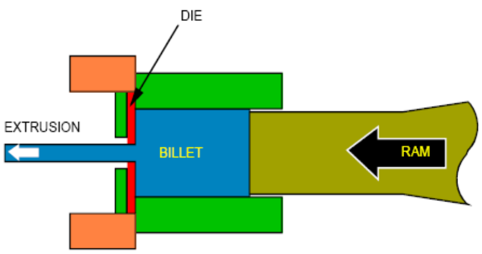

Fig. 2: Aluminum extrusion process

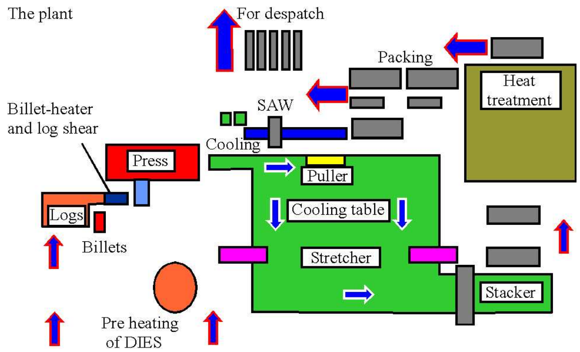

Fig. 3: Layout of a typical extrusion plant

Each value calculated by the drive electrical and process parameters can be transferred by the communication link to the PLC to initiate the required operation as required. Extrusion profiles from 0.1-1.40 kg m^{-1} and up to 45 m long are pulled out of an extrusion press at a predefined force. This was originally the task of three 7.5 kW linear motors operating in series, in torque mode. The torque can be changed manually and discrete-wise only in steps controlled by a rotary switch. Only six steps of control were available. That means, there was no way to increase or decrease the extruded profile pulling force smoothly. Also, linear motors had increasing problems with reliability. Problems with the sliding power feeders, due to puller movement up and down the track of extrusions, cause high frequency of breakdowns. Power feeders for linear motors were continuously a source of trouble and breakdowns due to wear and misalignment. Such problems limit the maximum speed of puller return to press side at idle phase increasing considerably the idling phase of extrusion cycle, thus reducing the productivity of the whole production line. The linear motors have been replaced by a wire rope pulley driven by a standard AC squirrel cage induction motor controlled by a high performance AC drive with Direct Torque Control (DTC) technology. Achieved benefits include improved extrusion process speed, controllability of extrusion pulling force, repeatability, reliability, reduced breakdown and a reduction in the overall maintenance costs of the extrusion production line.

Extrusion puller drive system: Extrusion puller is shown in Fig. 4. Statistics show that most of the motors in industrial use have only simple electromechanical switching form of control. This results in huge industry costs in maintenance and equipment replacement. Fitting soft starters could reduce these costs dramatically.

Fig. 4: Extrusion puller

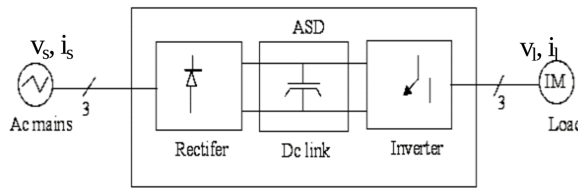

Fig. 5: A standard AC VSD

In conveyor systems, too, loads may be displaced or damaged on startup and products may become contaminated. Extrusion machines benefit from variable speed control, since frequently their speeds must change to optimize the process for improved product quality, production speed or safety[2]. Also, the controlled acceleration provided by a Variable Speed Drive (VSD) allows the extrusion puller to accelerate smoothly to prevent damage or breaking the extruded profile. For this application the electrical VSD offers the combined benefits of high performance, high efficiency and low maintenance[3,4].

As an extrusion bar appears from the extrusion die, the puller jaws locks on, the puller drive synchronized with extrusion process is started in torque mode and pulls extruded profiles with constant force. This pulling force is large for larger section and less for smaller section. This is to keep the extrusion straight above the slat conveyor whilst it is hot, with the pulling force ensuring that the shape and straightness is consistent each time[2]. As the extruder ram moves through its cycle, the puller drive, still in torque mode, moves the puller back along its track away from the extruder for about 45 m, depending on the extruded section, then stops. The extruded bar is then cut and cross transferred from the slat conveyor. The puller switches to speed control and accelerates back to the start position, slowing near to home and stopping at precisely the right spot in front of the extruder. A popular way to produce required linear motion from a rotary motor, the rope and pulley system typically has its thrust force capability limited to the tensile strength of the steel rope.

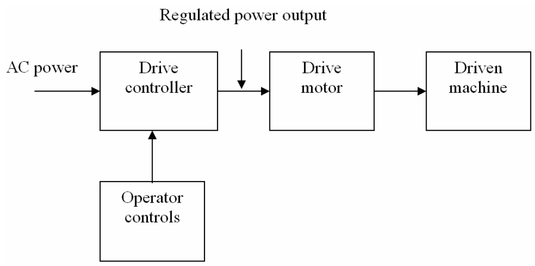

Fig. 6: Functional block diagram

Figure 5 shows the basic function of a VSD is to control the flow of energy from the mains to the process through the motor shaft.

Figure 6 shows the functional block diagram of a VSD drive[5]. To control the flow of energy we must therefore, ultimately, control two physical quantities: Torque and speed of the shaft. In practice, either one of them is controlled: "torque control" or "speed control". When the VSD operates in torque control mode, the speed is determined by the load. Likewise, when operated in speed control, the torque is determined by the load[6].

A standard 4-pole 400 V induction squirrel cage motor selected for this application. It will be controlled in speed mode of control from zero speed to speed near its synchronous speed of 1500 RPM. This type of induction motor operation is very much faster than the linear motor and is considerably more accurate. Starting torques up to 200% of full load rated torque guarantee reliable starting of even the heaviest loads. Operator sets the torque within the AC drive from a control desk. The drive start and stop commands are received automatically during production process over the communications network from the Programmable Logic Controller. The automatic start feature outperforms the flying start and ramp start features found in traditional AC drives and, with DTC, there is no restart delay. To prevent massive acceleration in the event of a rope break, the AC drive has current limit functionality. The extrusion puller drive in torque control mode of operation run as a constant torque system where the machine's torque requirement is independent of its speed. The ability of the AC controller to maintain a constant volts/Hz relationship is ideal from a motor standpoint. This permits operation of the motor at rated torque from near standstill to rated speed. Figure 7 shows the relationship between torque, horsepower and motor speed. Most of variable speed drives feature a torque limiter to protect the drive and the machine from torque overloads. In this application the torque limit is adjusted to 150 % of rated current to allow extra momentary torque for breakaway, acceleration or cyclic overloads. The selected drive system is capable of sustaining this torque overload for one minute or less.

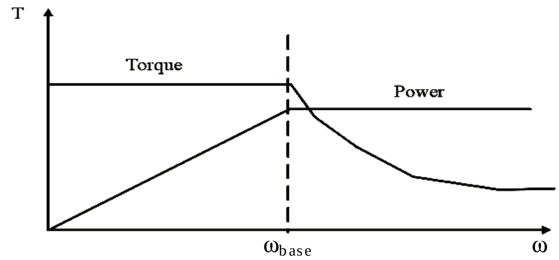

Fig. 7: AC motor operation regions

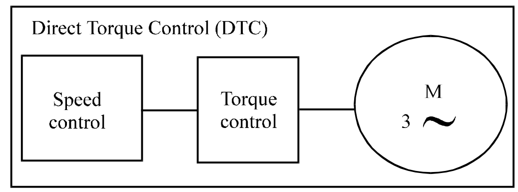

Fig. 8: Control loop of an AC Drive using DTC

Direct torque control: AC motors running on an AC line operate with a constant flux (Φ) because voltage and frequency are constant. Motors operated with constant flux are constant torque. Actual torque produced, however, is determined by the demand of the load. The selected AC drive is capable of operating a motor with constant flux (Φ) from approximately zero (0) to the motor's rated nameplate frequency (50 Hz). This is the constant torque range. With the DTC technology, field orientation is achieved without feedback using advanced motor theory to calculate the motor torque directly and without using modulation. The controlling variables are motor magnetizing flux and motor torque[7].

With DTC there is no modulator and no requirement for a tachometer or position encoder to feed back the speed or position of the motor shaft. Control loop of an AC drive with DTC technology is shown in Fig. 8. DTC uses the fastest digital signal processing hardware available and a more advanced mathematical understanding of how a motor works. The result is a drive with a torque response that is typically 10 times faster than any AC or DC drive. The torque response is the quickest available. The dynamic speed accuracy of DTC drives will be 8 times better than any open loop AC drives and comparable to a DC drive that is using feedback. DTC achieves trip-less operation by controlling the actual motor torque.

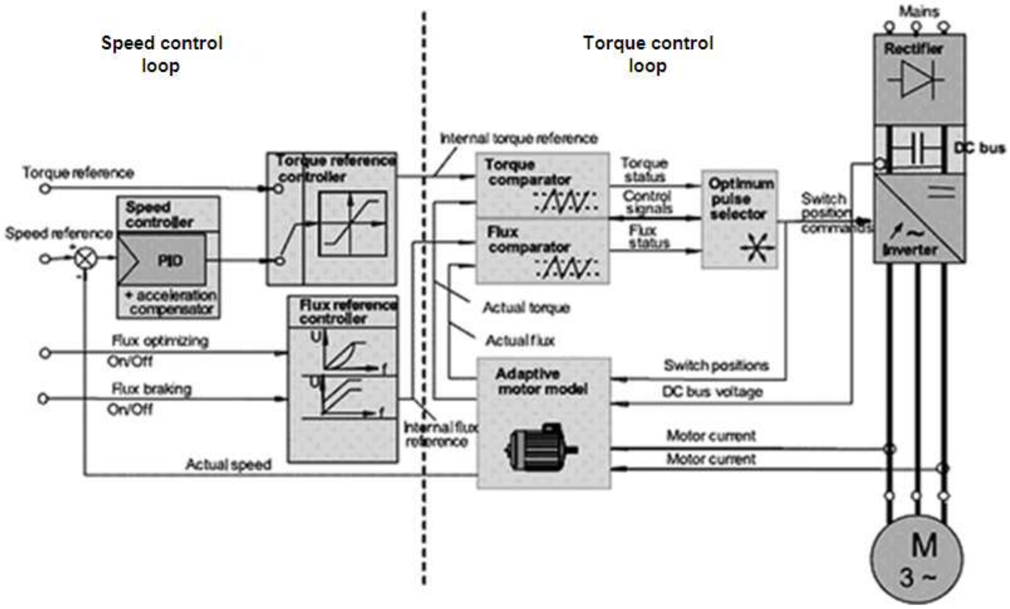

Fig. 9: Complete block diagram for Direct Torque Control (DTC)

Open-loop DTC drives have replaced traditional DC drives and latter flux vector controlled AC drives. Figure 9 shows the complete block diagram for Direct Torque Control (DTC). Motor speed is limited only by the maximum inverter output frequency, load torque requirements and the mechanical integrity of the motor. Torque reference is given through analogue input as a current signal. By default, 0 mA corresponds to 0% and 20 mA to 100% of the rated motor torque. Speed reference (RPM) is given through another analogue input as a voltage signal in the range of 0...10 V DC. Selection between speed and torque control mode, start/stop and direction commands was selected through digital inputs with 24 V DC supplied from the inverter. Actual signal values are measured or calculated by the drive and they cannot be set by the user[8].

MATERIALS AND METHODS

The parameters used for design of the implemented drive system were fully satisfying the production process requirements. A rope and pulley system comprising a 835 mm diameter driving pulley and a 44:1 gearbox with the motor's input speed at 1500 rev min^{-1} were used.

Calculating the peak force required is simply a case of adding the following components together:

$$F_p = F_a+F_f+F_g$$

Where:

F_p = Peak force

F_a = Force required for acceleration, which can be found using Newton's equation:

$$F_a = M*a$$

M = Mass [Kg}

a = Acceleration required [M sec^{-2}]

F_f = The frictional force, which can be calculated by the following expression:

$$F_f = m*g*\mu$$

g = 9.81 M sec^{-2}

μ = 0.0005-0.003; coefficient of friction for a roller bearing

F_g = The gravitational force. In this example the force is zero because the load is supported by the bearings

The next step is to calculate the continuous force requirement. The RMS force is the average force from the motor. As the acceleration interval many times less the total cycle time, we will consider the friction force only and calculate the motor torque which can apply this force continuously in constant speed mode of operation, or sum of this force and traction force required in the constant torque operation mode.

As double-rope is used, the required force will be obtained by dividing the total force by 2. Thus, the torque required and to be applied to driving pulley shaft can be calculated as:

$$\tau = \frac{F_{rms}}{2} * R$$

where, R is the driving pulley radius[M].

Considering gearbox with gear ratio (n), this torque referred to motor shaft will be:

$$\tau_m = \tau * n$$

The motor power required can be calculated from the known relationship:

$$P = \tau_m * \omega$$

where, ω is the angular velocity of motor calculated as follows:

$$\omega = \frac{2\pi\, n_m}{60}$$

n_m is the motor revolution $\min^{-1}$:

$$n_m = \frac{v}{2\pi R\, n}$$

where, v is the linear velocity of puller machine.

RESULTS

A puller machine drive included three 7.5 KW linear motor was replaced by a 4 kW AC induction squirrel cage motor with direct torque control technology. This drive provides means for an induction motor control in two operation modes: Speed control and torque control. Implementation of such technology in industrial automation saves consumed energy by 18%, payback period of this drive operating 6000 h year^{-1} is less than five months. Idle time in each production cycle reduced by 60%. This increases productivity and decreases energy consumed for unit production of finished product. Breakdown time and maintenance activities on the related equipment considerably reduced. No doubt, quality improvement was the main achievement of this implementation. It is possible with constant torque operation to keep the extruded bars away from scratches and dimensional deformations due to changes in applied pulling force.

DISCUSSION

Extruders always looking for continuous improvement of aluminum extrusion equipment, allowing to achieve high-level results. The optimization of every production step, a great care about the customers' problems, a flexible and dynamic organization: these allow to offer customers aluminum extrusion profiles which is produced with the best efficiency, precision and quality results. The improvement of production line performance started with investigations and finding of problem sources. The puller machine was found as a major cause for breakdowns, increased idle phase and reduced quality. These problems were solved by replacing the linear drive system of puller machine by AC drive with direct torque control. This saves valuable space at the side of the equipment, as will be appreciated particularly when a new system needs to be accommodated in an existing production environment. The new rigid design provides vibration-free movements.

The PLC supervisory system has been developed in order to solve the requirements of automatic control and production optimization of an aluminum extrusion line. The process supervision system was connected with the different components of the extrusion line by means of a standard serial connection (RS232).

The new drive system has brought immediate benefits, including greater flexibility, the ability to produce even more complex sections and improved quality.

CONCLUSION

In this study, an improvement of extrusion puller drive system was presented. The chosen drive system was used to improve the production line total performance and to reduce breakdown times. The operation of the extrusion puller driven by a standard AC drive with direct torque control proves the advantages of implementation of such advanced technology in the field of extrusion industry. The results indicated that DTC technology was a good choice for control of the extrusion puller operating consequently in speed and torque control modes. A potential profits were gained due to change: a decrease in the consumed energy costs, an increase in productivity and a decrease in maintenance costs. Thus, the direct torque control technology can be strongly recommended for successful implementation in all industrial fields with similar operation requirements, where both speed and torque modes of operation are required.

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