ELECTROHYDRAULIC SERVOMECHANISM FOR DRIVING THE REELS OF COIL WINDING MACHINES SPECIFIC TO WIRE ROLLING MILLS

Ph.D. Teodor Costinel POPESCU[1], Ph.D. Marian BLEJAN[2], Ph.D. Ioan LEPĂDATU[3]

National Institute for Optoelectronics, INOE 2000-IHP Bucharest,

e-mail address: [1]popescu.ihp@fluidas.ro ; [2] blejan.ihp@fluidas.ro ; [3]lepadatu.ihp@fluidas.ro

Abstract: *The drive system of a winding machine, mounted on the production line of a wire rolling mill, must perform at the same time driving in a rotary motion of the drum on which the wire is wound and linear displacement of the wire reeling device. On the dynamic performance of the operation of this system depends largely the quality of wire winding in the coils delivered to the beneficiaries, reducing losses caused by re-melting the wire improperly wound and productive capacity of the mill.*
This system is usually of two types: electromechanical, based on variable speed electric motor and ball valve screw or electro-mechano-hydraulic, without control loop, based on variable speed electric motor, speed reduction gear and hydraulic drive system on-off type. Typically, the drum which the wire is wrapped around is operated electromechanically for both types of systems, and the reeling device, which moves linearly, along the drum, the wire coming out of the mill, is driven by a ball screw, for the first type, or hydraulically, without control loop, for the second type.
The authors of this material have developed and put into operation an electro hydraulic servomechanism for driving the reeling head that allows controlling its position and speed by means of an electro hydraulic control loop.

Keywords*: reeling device, coil winding machine, electrohydraulic servomechanism*

1. Introduction

The production practice of wire manufacturers, such as SC ALRO SA Slatina, shows that the drive systems of drums cause no problems in operation and exploitation; they achieve both a satisfactory uniformity of the rotation, for each layer of wire coiled, and a corresponding reduction in rotational speed at the beginning of each new layer of wire that will be wrapped. The two known types of drive systems of the reeling head however cause problems, regarding correlation with the rotational speed of the drum, for the first type, and problems of reliability, for the second type. In this context came the demand from SC ALRO SA, submitted to INOE 2000-IHP Bucharest, to develop a new solution for driving, operation and control of the reeling head, with operating parameters better than the existing solutions [1]. Achieving this new solution for control of the reeling head considered the operating conditions of winding machines, specific to wire rolling mills existing in Foundry Division at ALRO Slatina.

2. The operating conditions of winding machines specific to wire rolling mills

The winding machines, specific to wire rolling mills at ALRO Slatina, operate within foundry divisions where aluminum bars and wire are manufactured.
The flow of production of these divisions is continuous, almost totally automated and it includes preparation of raw material in furnaces or electrolysis baths, feeding bar rolling mills and wire rolling mills, storage of finished products, namely wire bars and coils.
A wire winding machine is the terminus point of a production line of aluminum wire. It contains two drums, operated successively, by means of a variable speed electric motor and a reduction gear with two output shafts.
The wire coming out of the mill is directed along a groove towards the evenly rotating drum. The constant value of the speed depends on the diameter of wire that will be wrapped around the drum, namely: **9.5; 12; 15; 19.3 mm**.

Fig.1. Wire production flow (back to front):
furnace, rolling mill, gutter, winding machine with two drums and two reels.

The technology of winding includes the next steps:

a) Before winding wire around one of the two drums, it begins to rotate uniformly accelerated, until it reaches the constant speed specific to the diameter of wire coming out of the mill. Simultaneously, the device for wire reeling on the drum, electro hydraulically actuated, moves to the right end and waits for the wire from the rolling mill.

Fig.2. Two drum coil winding machine idle: both reels stationed at the flange on the left of drums; **right, foreground** –gutter through which the wire comes from the rolling mill; **right, background** - gutters through which the wire is directed to the drums, where it is taken up by the reel.

Fig.3. Reeling head, driven by a hydraulic cylinder with fixed bilateral rod and mobile liner.

b) When the wire coming out of the rolling mill, directed along the gutter by the guide in the reeling head, comes into contact with the drum, there is actuated a device for clamping the end of the wire on the drum. The reeling head is stationary during winding the first spire, then it moves to the left. It contains two limiters, one of which controls the duration of standing and the other controls change in direction of reeling head motion (at the end of stroke). Movement of the reeling device is correlated with the drum rotational speed as follows: **during one rotation of the drum, the reel moves uniformly and continuously, along a distance equal to the diameter of the wire and 0.7...0.8 mm additionally. x**
c) On completion of winding of the first layer of wire around the drum, there is ordered reversing of reel movement, by activating the other proportional electromagnet of the control directional valve which actuates the cylinder of the reel. Simultaneously, the drum rotational speed decreases, so that the tangential speed of the wire on the drum to be steady.
d) At each change of layer, the winding diameter is changed and, from the automation panel of electric motor operation, lower speed of the drum is ordered, so that the wire speed remains constant. Thus, **for the first layer of wire wrapped with 9.5 mm diameter, the displacement speed of the reel is 1.8 m / min, and the drum rotational speed is 180 rev/min.**
e) During the winding the drum is weighed; when the scale shows 2.1 ... 2.2 tons, order is made for the drive of the second drum, respectively for the displacement of the second reel to the standby position.
f) The wire on the wound drum is cut by means of a guillotine, then it is directed to the second drum, on which winding continues.
g) The duration of wire winding around the drum is approx. 60 minutes. In this period of winding time is sufficient for manually binding the wound coil, manual removal of a flange of the drum, by unscrewing a large nut, extraction of the coil from the drum, using a hydraulic device, its moving by means of the running bridge to the storage location, reassembling of the drum flange and preparing it for a new winding cycle.
h) Working is non-stop, in three shifts, and the number of wire rolling mills, each serviced by two drums, and the wire diameter are set according to the demands.
i) In case of failure in operation, poor winding quality and at the end of each coil, the wire is cut and directed to a chopper, until the fault is rectified, or winding is switched to the other drum.

j) The wire wastes resulting from chopper are melted down and sent back into the manufacturing cycle.

Fig.4. Wire coil bound, taken from the drum and stored for delivery.

3. The electro hydraulic servomechanism for control of the reeling head

In the division at ALRO, each reel of a winding machine, which services a wire rolling mill, is driven by a hydraulic cylinder with bilateral fixed rod and mobile liner, powered by an adjustable pump, directly driven by the speed reducer. Along the supply lines of cylinder there are mounted adjustment valves and throttles, from which is made the setting of cylinder speed in both directions of travel. For each diameter of wire is made an adjustment of the pump. The actuating directional control valve of the cylinder is on/off type, not proportional. In these circumstances, one loses much time for adjustments, and the quality of wound coils is poor, which results in multiple wastes (which are re-melted).
To test the proposed solution, in December 2012, at ALRO, INOE 2000-IHP Bucharest mounted on a drum of a winding machines an own system for operation of the reel, type electro hydraulic servomechanism, and on the other was kept the existing home solution. This system worked and compared with the classical solution proved to be more reliable (higher quality in winding wire, less wastes).
From the original solution, existing at ALRO, there has been preserved only the hydraulic cylinder with fixed bilateral rod and mobile liner. The structure of this electro hydraulic servomechanism for control of the reeling head includes:
The pumping unit, which has a modular design and comprises: an oil tank (with lid, filling opening and vent, level gauge and drain plug) on the lid of which is bolted a plate of hydraulic mechanical joints, inside which, by means of a grip mechanical coupling, is made coupling between the shaft of a fixed gear pump, mounted submerged in the tank, and the shaft of an electric motor, of constant speed, fitted to the top of the plate. Also inside this plate there are embedded a check valve, acting as anti-cavitation for the pump, a pressure control valve with direct control and a 2/2 normally closed directional control valve, which protects the pump at starting, not allowing it to start under load. In the proximity of the plate of mechanical hydraulic joints there is mounted an adapter plate, which distances from the electric motor the other modules of the pumping unit, respectively the plate incorporating the return filter and the mounting plate of the proportional directional control valve Dn6. On the mounting plate of the 4/3 proportional directional control valve, Parker production, there is screwed a glycerine pressure gauge with measuring range 0-100 bar.

Fig.5. The existing pumping unit and the shoe and drum brake of the reducer: there have been blocked the pipes by which this group supplies the hydraulic cylinder of the reel; a speed transducer was mounted on the drum shaft of the reducer.

Fig.6. The modular pumping unit fitted with proportional directional control valve (IHP).

Fig.7. Drive cylinder of the reel: position and speed cable transducer (IHP).

The hydraulic cylinder with bilateral rod and double acting (existing subassembly) is connected by means of two 12x1 pipes to the consumers A and B on the mounting plate of the proportional directional control valve.

Thermostatic control of hydraulic oil in the installation is provided by a system comprising the following components: a dedicated module of the electric and automation panel; a resistance for heating the oil, immersed in oil and attached to the front wall of the tank; a winding tube of copper 14x1 pipe, oil immersed, with the ends attached to the tank cover and a normally closed electro valve on the inlet of the cooling water in the winding tube; a temperature sensor mounted immersed in oil and attached to the tank cover.

Automating the operation of the reel is made by the following procedure:

- on the existing hydraulic cylinder, actuating the reel, is mounted a **position transducer**, which allows precise monitoring and control of **travel speed** of hydraulic cylinder liner and **instantaneous position** of the liner, throughout the active displacement stroke; position and velocity control is carried out by means of an electro hydraulic control loop**;**

- **drive of the hydraulic cylinder** is carried out through the hydraulic proportional directional control valve, which actuates the hydraulic cylinder in a displacement closed loop;
- **travel speed** of the reeling head is *v* [mm/s] = *d* [mm] * *n* [rev/s] , where *d* is diameter of the wire which is wound around the drum, and *n* is rotational speed of the winding machine drum (in the period required for winding one spire around the drum, the reeling head, thus the cylinder liner, performs a stroke equal to the wire diameter);
- **the information on the drum rotational speed** is taken from a variable reluctance speed transducer, mounted on the shaft of winding machine reducer;
- **there has been used an TWIDO** (Schneider Electric) **programmable logic controller (PLC)** equipped with an LCD console for monitoring and introduction of operating parameters of the reeling head (for example, the diameter of the wire to be wound around the drum). On customer request, the programmable logic controller (PLC) can be provided with a data communication line, type RS232/485, CANopen or Ethernet, with MODBUS communication protocol (RTU or ASCII).

The electric and automation board includes: the electrical power components, namely the contactors and the safety devices specific to the electric motor actuating the fixed flow pump and to the hydraulic oil thermostatic control system; ON / OFF switch; HAZARD WARNING mushroom push button; optical indicators; temperature controller; TWIDO programmable logic controller.

Fig.8. The electric and automation board (IHP).

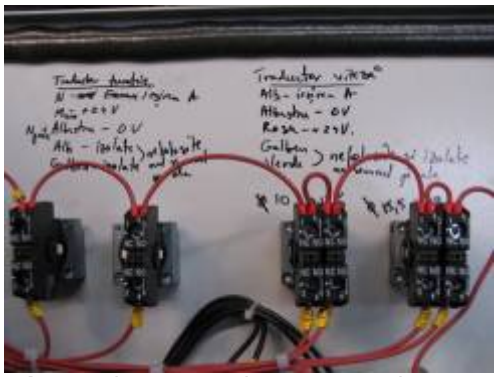

Fig.9. Wire connections at transducers, made on the inner surface of the board case (IHP).

Fig.10. The outside of the board case (IHP): wire diameter selection keys; reel manual displacement control; operating mode switching control; start; stop; signaling lamps.

4. Schematic diagram and technical characteristics of the product

The schematic diagram, fig.11, refers only to the operation of a single reel, but it can be also extended to two reels, keeping the same hydraulic unit to power both hydraulic cylinders, as they work almost continuously in sequence and only a short sequence at the same time (at the end of winding around a drum and preparation of winding around the other drum). This schematic diagram can be materialized for all 7 double winding machines of wire rolling mills at ALRO and is suitable for both the introduction of the reel operating parameters and the monitoring of the production of wire.

The structure of the diagram in Figure 11 is as follows: **1**- oil tank, fitted with tight cover, level indicator, filling and ventilation opening, drain plug, with $V_{max.}$= 30 l and $V_{effective}$=22 l; **2**- oil heating resistor, with N=1330 W; **3**- winding tube for cooling the water inside the copper 14x1 pipe; **4**- normally closed electro valve, G1/2", Δp_{max}= 6 bar, supply voltage 24 V DC; **5**- temperature sensor Pt 100; **6**- gear pump, capacity 3.65 cm^3/rev, maximum pressure 250 bar, inlet filter; **7**- electric motor, 220 V, single phase, 0.55 kW, 1400 rev/min; **8**- grip mechanical coupling; **9**- pressure control valve 0...60 bar; **10**- check valve, opening pressure 1 bar; **11**- 2/2 hydraulic distributor, normally closed, operated electrically and manually, which protects the pump at starting. **12**- intermediate plate with role in fastening and mounting the pumping unit; **13**- return filter, filtration fineness 10µm, equipped with bypass valve; **14**- pressure gauge wit glycerine, measurement range 0...100 bar; **15**- proportional hydraulic directional control valve,

4/3, rD6, closed center; **16**- (existing) hydraulic cylinder, bilateral fixed rod and mobile liner, $Ø_{piston}$ = 65 mm; $Ø_{rod}$ = 48 mm; Stroke = 870 mm; **17**- cable position transducer, for monitoring and control of hydraulic cylinder speed; **18**- speed transducer of winding machine drum; **19**- (existing) end of stroke signaling devices, controlling the change of the direction of hydraulic cylinder displacement.

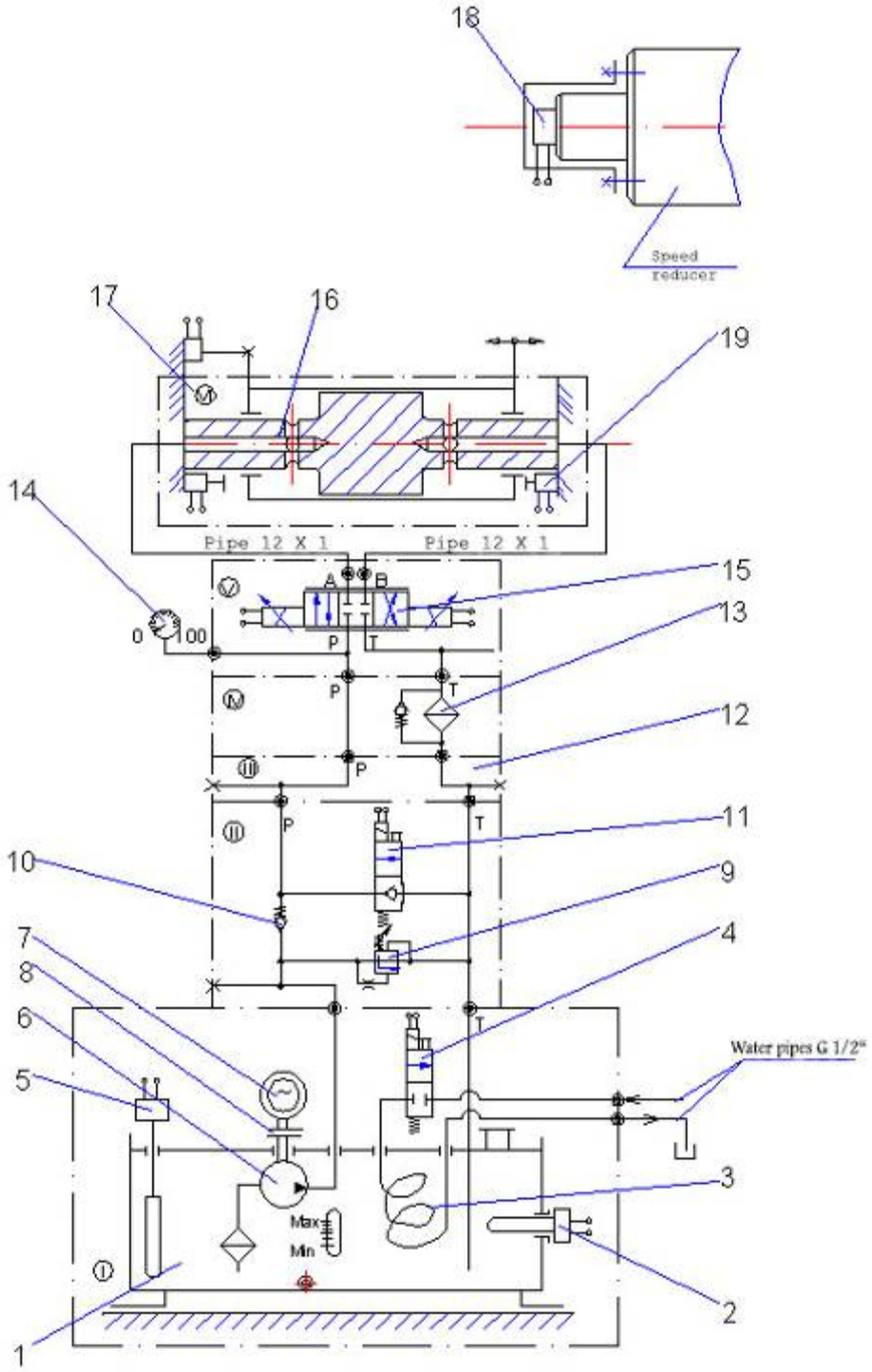

Fig.11. Schematic diagram of the electro hydraulic servomechanism for driving the reeling head

5. Description and operation of the electro hydraulic servomechanism driving the reeling head

At the level of the pumping unit, mechanical energy from the electric motor shaft (the wedge of speed and torque) is converted into hydraulic energy (the wedge of flow and pressure) materialized by the oil flow, routed from the pump discharge pipe to the hydraulic cylinder. The amount of oil pressure, depending on the load of the hydraulic cylinder, can be adjusted by manual operation of the pressure valve.
When starting the pumping unit there is operated automatically (or manually), for 4-5 seconds, the hydraulic 2/2 directional control valve, normally closed, which closes the flow path to the hydraulic cylinder and allows free discharge (no load) of the pump to the tank.
At the level of hydraulic proportional 4/3 directional control valve, closed center, on the center position, without drive, the holes P (pressure, from pump), T (tank), A and B (consumers, that are connected to the hydraulic cylinder) are closed (not communicating with each other). When supplying one of the two coils of directional control valve, its slide valve moves, left or right, with a stroke proportional to the intensity of the supply current of the coil, and connects ***P to A***, respectively ***B to T***, for a direction of travel of the hydraulic cylinder or ***P to B***, respectively ***A to T***, for the opposite direction of travel.
The distribution system of the hydraulic oil, to the hydraulic cylinder, ensures: proportionality between actuation of proportional directional control valve in current and speed of movement of the hydraulic cylinder, change of the direction of movement of the hydraulic cylinder, starting and stopping of the hydraulic cylinder.
The closed loop of electro hydraulic control, achieved by means of the speed transducer, displacement transducer and the PLC, controls the travel speed of the hydraulic cylinder by maintaining the linear static characteristic current-flow of the proportional directional control valve in a constant and sufficiently small deviation range.
At the level of the hydraulic oil thermostatic control system, when the temperature sensor detects values lower than 38^{o}C, there is ordered starting of supply of the electrical resistance, and at values of the oil temperature higher than 42^{o}C there is ordered opening of the electro valve for access of cooling water into the winding tube of copper pipe.

Conclusions

- Tests conducted during putting the product into service, as well as its subsequent exploitation, over a period of 3 consecutive months, have clearly demonstrated the advantages of this type of drive, command and control of the reeling head, compared to the existing solution: higher quality of wire winding around the drum; decrease of scraps of badly wrapped wire, that is re-melted; thermostatic control of the hydraulic oil temperature; the possibility to set the diameter of wire that is to be wrapped; on customer request, the possibility to monitor, record and control the production of wire through a data communication line.
- The only drawback of the product is related to random blocking of the slide valve of proportional directional control valve, due to impurities from the environment, which can not be prevented from entering the hydraulic oil. The solution for removing this obstacle is to take three steps: installing a filter on the hole P of the proportional directional control valve; an increase of 10 bar of the maximum pressure adjusted (from 30 bar to 40 bar); choosing a higher gear electric driving motor.

REFERENCES

[1] INOE 2000-IHP Bucharest, S.C. ALRO S.A. Slatina, "Centrală Hidraulică pentru Bobinatorul Laminorului de sârmă" (Hydraulic plant intended for the bobbin winder of a wire rolling mill), Contract No. 4600007204/30.08.2012, Construction documentation, 2012