

# NEW CONCEPT OF ELECTRICAL DRIVES FOR PAPER AND BOARD MACHINES BASED ON ENERGY EFFICIENCY PRINCIPLES

by

**Borislav JEFTENIĆ, Saša ŠTATKIĆ,  
Milan BEBIĆ, and Leposava RISTIĆ**

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*In this paper, it is described how the reconstruction of the facility of paper machine has been conducted, at the press and drying part of the machine in June 2001, as well as the expansion of the Paper Machine with the "third coating" introducing, that has been done in July 2002, in the board factory "Umka". The existing old drive of the press and the drive of drying groups were established as a Line Shaft Drive, 76 m long. The novel drive is developed on the basis of conventional squirrel cage induction motor application, with frequency converter. The system control is carried out with the programmable controller, and the communication between controllers, converters, and control boards is accomplished through profi-bus. Reconstruction of the coating part of the machine, during technological reconstruction of this part of the machine, was being conducted with a purpose to improve performance of the machine by adding device for spreading "third coating". The demands for the power facility were to replace existing facility with the new one, based on energy efficiency principles and to provide adequate facility for new technological sections. Also, new part of the facility had to be connected with the remaining part of the machine, i. e. with the press and drying part, which have been reconstructed in 2001. It has to be stressed that energy efficiency principles means to realize new, modernized drive with better performances and greater capacity for the as small as possible amount of increased installed power of separate drives. In the paper are also, graphically presented achieved energy savings results, based on measurements performed on separate parts of paper machine, before and after reconstruction.*

Key words: *paper machine, energy efficiency, electric drive, frequency converters, PLC control*

## Introduction

The board machine in the board factory "Umka" is one of the biggest machines of that kind in this region, probably the biggest, considering its capacity, dimensions, the real attained annual production, and installed power. Construction of this machine was performed by stages, in long time intervals. As a consequence of this, two different prin-

ciples of motion, accomplished in two different technological periods were applied at the machine before reconstruction has done in 2001. On fig. 1 is shown the principle of motion applied at the machine before the reconstruction. The couch section of the machine and the final part of the process, coating part, are operating using independently controlled drives with direct current motors (DC motors) and thyristor rectifiers. This part of the drive was installed during the expansion and reconstruction of the machine in 1977. The central part of the machine was operating by the use of central shaft, the mechanical transmission (line shaft) with one DC motor drive. This kind of mechanical energy transmission was inherited from the beginning of the machine construction in the 60's of the last century. Both principles of motion have their own advantages and disadvantages that is well known in literature.

The Line Shaft Drive (LSD) has a number of disadvantages compared to separate drives (SD) [1]. Some of them are:

- motor units are big and expensive, therefore they are not easily replaceable,
- LSD has poor efficiency,
- LSD is prone to wear, generates vibration and noise,
- practice indicates that the maintenance costs of LSD, regardless of the concept, are exceptionally high,
- this principle of motion is one of the crucial limiting factors for the increase in speed of the machine, and thus the increase in production capacity,
- a problem in changing the production program is occurring due to heavy and sluggish adjusting of tensions,
- it is not possible to control drives independently, for example, increase in speed in a short time interval due to elimination of web (loop) relaxing, or reversing when cleaning the accumulated mass or paper, and
- disturbances at the one end of the machine are transmitted to the other, due to shaft torsion. As a consequence, the web ripping is occurred [2].

Obviously, there are some advantages of LSD:

- if decrease in speed is occurring at one drive due to load increase across the line shaft, the decrease in speed is occurring at the rest of drives in the same manner. As a consequence, the web ripping is avoided [3],
- load sharing between drives is inherently accomplished across the line shaft and the installed power is optimally used [4], and
- slipping and elasticity that are existing at flat belts, enable the amortization of load peaks and load balancing between drives with rigid mechanical coupling, using the felt and the press part of the machine.

The use of SD for paper machine motion, enables that some of mentioned disadvantages become exceeded and technology of paper production additionally improved, the first of all the increase of maximal speeds of the web, that directly influences the machine capacity. Meanwhile, new problems have appeared, especially in the field of control. It is necessary, when controlling a drive, to provide required synchronization and tension reference. Among the speed synchronization, the load sharing has to be provided at the drives with rigid and partially rigid coupling, that is typical for final phases of production, when the web is formed.

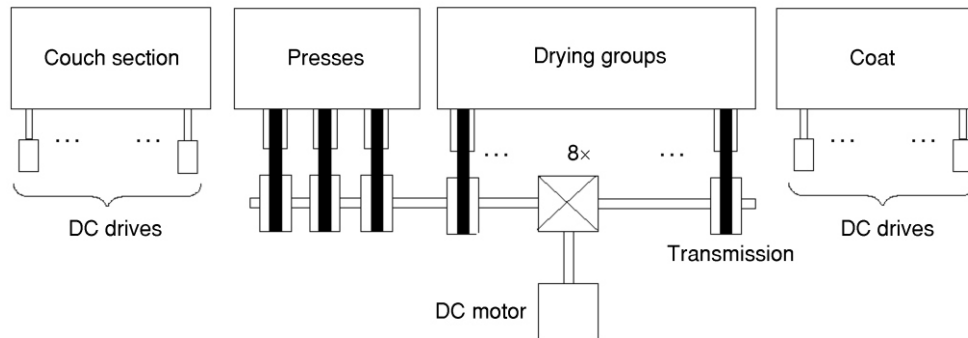


Figure 1. The principle of motion before reconstruction of the machine

### The new electrical drive for board machine

Starting from the reasons mentioned above and the latest positive experiences [5, 6], during the last reconstruction, the existing LSD is replaced with the SD, but now, with induction motors with frequency converters. The main shaft with all belts has been removed, as well as DC motor drive (350 kW) with the supplying thyristor rectifier. In the reconstruction of the plant, only the existing gear-boxes are kept. Their incoming shafts are coupled with induction motor drives. The conventional squirrel cage induction motors “Sever”, Subotica, Serbia, have been used, with the rated synchronous speed of 1500 rpm. Each motor is fed from a separate frequency converter DANFOSS, from the VLT 5000 series. The basic motor's and converter's data are given in tab. 1.

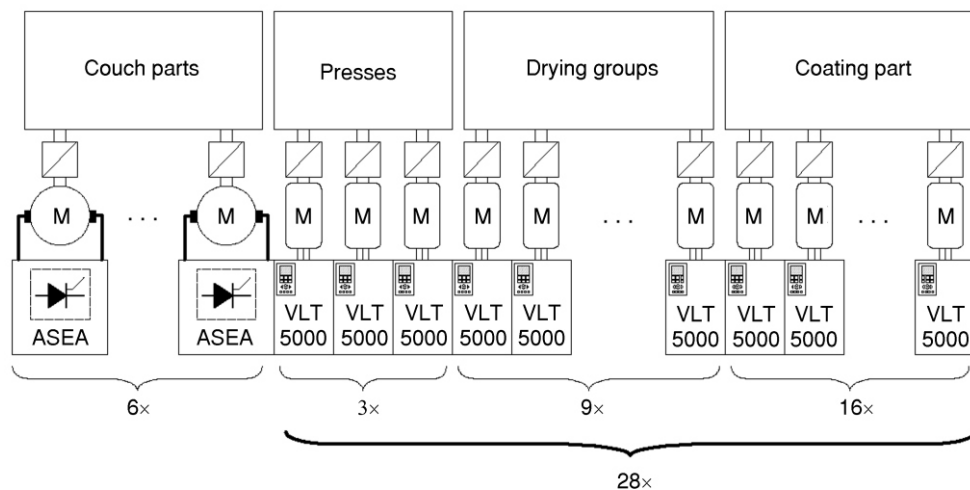
It could be seen from the given data, that the total installed power of new motors is 500 kW. That is 40% more than the power of DC motor used for motion of line shaft. That is consequence of many different facts. The first of all, self-cooled motors were used, that influences the choice of power. Second, in the case of SD, there is no possibility of load sharing between drives, owing to the fact that the motor has to be dimensioned for the most inconvenient case. Third, one of the basic reasons for the reconstruction is expansion of the machine capacity, which implies the speed increase of the drive, and that is also directly reflected to the required power of

Table 1. The basic data of motors and converters applied in the reconstruction of the press and drying part of the machine

Drive	Converter	Motor [kW]
I press	VLT 5052	45
II press	VLT 5052	45
III press	VLT 5075	55
I drying group	VLT 5060	55
II drying group	VLT 5042	30
III drying group	VLT 5042	30
IV drying group	VLT 5042	30
V drying group	VLT 5032	30
Drying cylinder	VLT 5075	75
VI drying group	VLT 5042	30
VII drying group	VLT 5042	30
VIII drying group	VLT 5060	45

**Table 2. Structure review of old and new drive of coating part of the board machine**

No. drive	Drive	Before reconstruction		After reconstruction	
		Converter	Motor [kW]	Converter	Motor [kW]
1	Calender	Thyristor rectific.	85	VLT 5075	55
2	Backing roll I	Thyristor rectific.	28	VLT 5042	30
3	Applicator roll I	Thyristor rectific.	DC	VLT 5016	11
4	Guide roll I	Thyristor rectific.	17,6	VLT 5016	11
5	Guide roll II		17,6	VLT 5042	30
6	Guide roll III		17,6	VLT 5042	30
7	Guide roll IV		17,6	Not fitted	–
8	Guide roll IV	No existed	–	VLT 5016	11
9	Guide roll V		–	VLT 5042	30
10	Guide roll VI		–	VLT 5016	11
11	Guide roll VII		–	VLT 5016	11
12	Backing roll II		–	VLT 5042	30
13	Applicator roll II		–	VLT 5016	11
14	Guide roll VIII		–	VLT 5016	11
15	Guide ropes	Thyristor rectific.	28	VLT 5042	30
16	IX drying group	Thyristor rectific.	28	VLT 5075	55
17	Reel	Thyristor rectific.	28	VLT 5075	55

**Figure 2. The motion principle of the board machine after reconstruction in the year 2002**

the drive. During the designing of the drive, the maximal, calculated speed is increased from 200 to 300 rpm (50%). However, this increase in the power amount is not directly proportional to the drive cost, because induction motors are two or three times cheaper than DC motors. Also, the self-cooled motors are significantly cheaper than motors with forced cooling. Finally, one has to keep in mind that the applied conventional motors can be easily found at the market.

Applied frequency converters belong to the latest generation of this kind of devices, and they satisfy all the required demands that could be requested from devices of the kind. Converters provide high quality and accurate control of drive speed in all working conditions, either in the case of speed reference changing or in the load changing conditions. Among that, the converters made by distinguished companies, include the protection system, for self protection and motor protection, for example, under voltage and over voltage protection, overload, overheating protection, *etc.* Those converters have been chosen, tested and successfully applied in few similar cases [4-6].

Within the reconstruction of the coating part of the board machine, experiences from earlier similar activities have been used [6-10]. The motion of the coating part of the machine before reconstruction was performed by ten DC motors, fed from thyristor rectifiers. Four motors for the drive of guide rolls were fed from one converter, while the other drives, calender, backing and applicator roll, guide ropes, IX drying group, and reel, were fed from separated converters. The control of drive speed was performed from the motor armature, while the guide rolls have performed combination of armature and field speed control. Before the reconstruction, two devices for measuring the force of tension (pressductors) were operating, the first of them was effected the tension of backing roll, while the other was effected the tension of IX drying group.

Within the reconstruction, all existing drives had to be supplied with new drive motors, but also the motion for new seven drives had to be provided. New drives are five guide rolls, and new pair, backing and applicator roll. One of the guide rolls from the old plant was put out of operating. In order to provide uniformity of motors, gear-boxes and converters at the coating part of the machine, motor gear-boxes made by company Bauer are chosen for all drives. Converters for all drives are Danfoss, series 5000, like in reconstruction of the press and drying part of the machine. A proper uniformity of drive power is also made, wherever it was possible, with the intention of providing sufficient quantity of stock of equipment. The structure review of old and new drive is given in tab. 2. The increase of power of new motors in comparison with old is a consequence of higher projected machine speed, in the amount of 300 m/min., with regard to the old (200 m/min.) and mentioned power uniformity. Figure 2 shows the principle of motion of the machine after the reconstruction 2002.

## Drive control

Paper and board machines require very complex control. The speed reference has to be kept at accurate level, a synchronized control of all drives too, as well as cascade speed forwarding from drive to drive, with ability of precise correction, in order to pro-

vide tension (“zug”). Furthermore, between drives in the part of production where the web is formed, it is necessary to supply the board tension force regulation, and load sharing, too [3, 6, 7, 10]. The conventional method for providing the tension force regulation and the load sharing, is with the use of force sensors, pressductors. Those devices are very precise, but expensive. The high accuracy of preserving tension force in the web is not necessary in the case of machine like this, but preserving the accurate load sharing between drives is necessary. To facilitate the stable drive operation, the adequate attention had to be paid to this problem.

The technology provider in the case of reconstruction of coating part of the board machine, company Jagenberg, two new force measuring devices has predicted additionally, that has to be integrated in the drive control system. Starting from the experiences obtained from the reconstruction of press and drying part of machine, within the project of the drive, it is determined to apply load sharing regulation (motor torque distribution) on other drives that are in the function of drawing or web guiding.

The total number of tension force measuring devices, pressductors, after reconstruction is four. The first of them, looking from the direction of web operation, influences the speed, tension of the first backing roll in other words, which has existed in the first configuration, too. The second, also existing, influences the drive 9 guide roll V otherwise, where the web inclusion is increased so it has gotten the part in operation of drawing roll. The third pressductor influences the second, new backing roll, and fourth pressductor influences the IX drying group. Load sharing, motor torque distribution otherwise, is applied between drives of V and VI group, VI and VII drying group, VII and VIII drying group, VIII drying group and the drive of calender. Additionally, torque distribution is applied between the drive of calender and the first guide roll (drive 4), as well as in the drive of the rest of guide rolls, with the exception of the guide roll V (drive 9).

Applying the combination of tension force control and load sharing between drives, the necessary stability of plant operation is attained [1, 7]. Figure 3 presents the scheme of the plant which is the subject of considered reconstruction. The scheme of the applied motor torque distribution concept is presented at fig. 6, while the fig. 8 presents the control strategy of tension force.

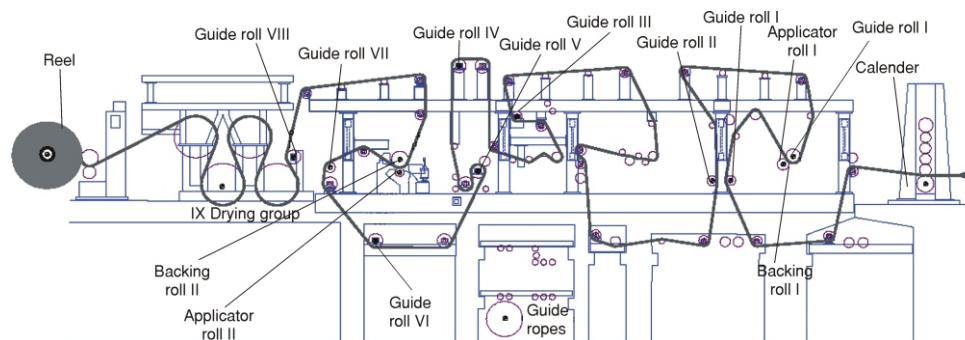


Figure 3. The principal scheme of the new drive at the part of the board machine

In order to supply high grade of drive control of the reconstructed press and drying part of the machine, for realization of the control system, high performance programmable logic controllers (PLC), Siemens S7-300, is used. In this case, 12 drive coordination, had to be provided, the same number of control boards, therefore all the converters are connected at profi-bus communication. This solution is quite contemporary, and nowadays represents the standard for control of systems of the type. Profi-bus communication is for the first time practically applied for the control in our country, in this project. Thanks to communication speed that offers profi-bus, beside the distribution of reference drive speeds in the controller, the regulation of load sharing between the last three drying groups in the series that is reconstructed (behind the drying cylinder) is applied. Controller is also supplying compact, reliable system of control, multiple smaller dimensions with reference to utilized solutions. Particularly, the ability of simple control has to be emphasized and very wide extent of abilities in supervision of whole drive operation. The previous fact provides fast disturbance detection, and as a result of that, efficient elimination of failures, in a short time. Figure 4 presents a principal scheme of reconstructed part of the drive of the board machine, with presentation of motor disposition and control system connection.

The control board consists of one operational panel, Siemens OP7, which tastars are used for the drive control. Two operating principles, or two modes of control exist. In the manual mode of operation, all drives operate individually, they can run at desired

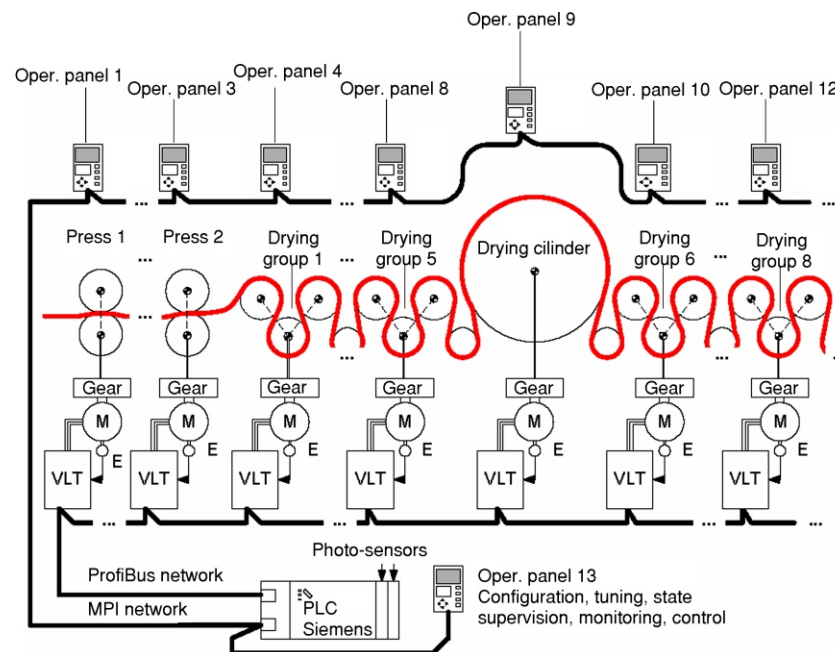
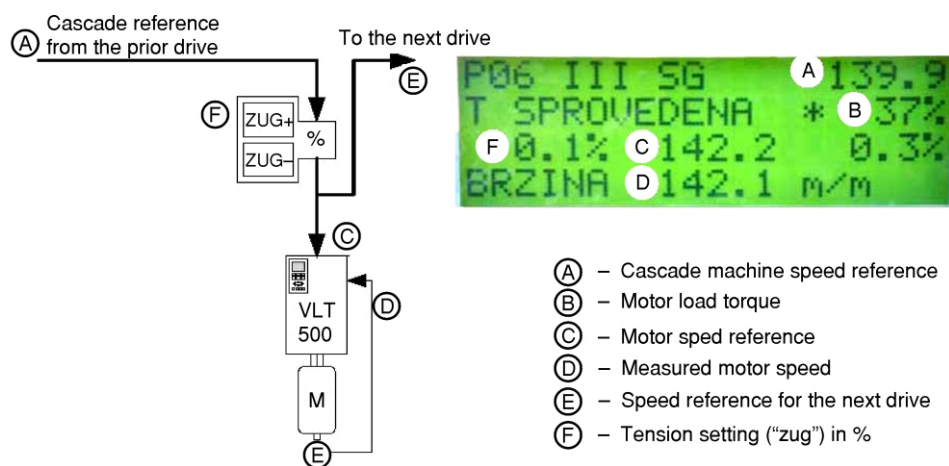


Figure 4. The principle scheme of new drive of press and drying groups



speed, and in two directions. The speed and the direction are chosen from the panel. This operating condition is suitable for cleaning and washing a machine, or releasing. In the automatic mode of operation, drives are operating at speed which is required for the entire machine, and tensions ("zug") are tuned from the appropriate panel and the "loop" elimination is additionally possible. Significant data for the drive operation can be read from panels, like speed, tension ("zug"), load, *etc.* In the case of some disturbance occurring in drive operation, or entire machine, messages are written at the panel, that inform operator about what has happened, with the purpose of faster disturbances elimination and standstill reduction. Beside this 12 control panels, two more panels are obtainable, one in the electro hall, and the other in the main control room. Both of them offer the ability to operators and maintenance services to have an eye in the drive operating condition, so as to entire machine.

The special problem in drive control of the machine realization was the fact that the new drive with contemporary digital control is inserted in the middle of the machine, between two parts of the drive with conventional analog principle of control. If the problem wouldn't be solved in the proper manner, operation of the machine wouldn't be possible: permanent web ripping would occur at the crossing place from the part of the machine which drives the old drive to the part which drives the new one and *vice versa*. Thanks to good knowledge of both drives, applied converters performances and programmable controllers, as well as profi-bus communication, this delicate problem is suitably solved. The special controller is set for synchronous operating control of these two drive parts established in a different way. This controller is established with the combination of digital and analog technique, and presents the original solution of the problem.



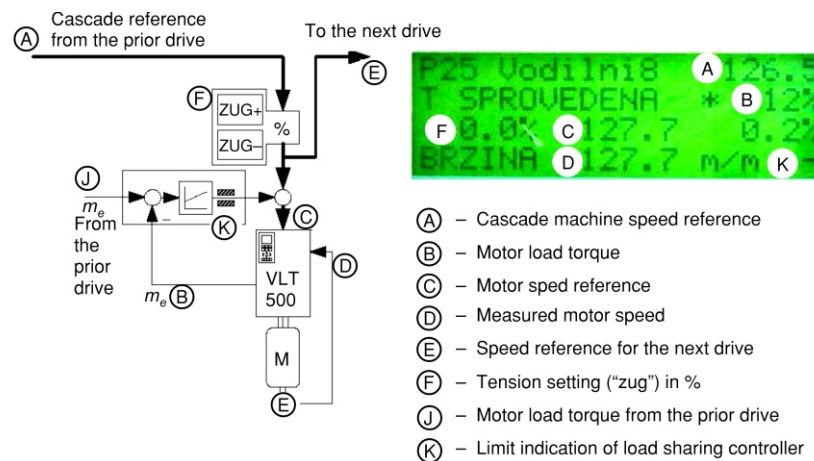
**Figure 5. Block diagram and presentation of characteristic screen for first group panel (This mode of control is established at the part of the drive where the web is wet and unformed, near to drying cylinder)**



For the realization of the control system in the case of coating part of the board machine reconstruction, the same high performance controller (PLC), Siemens S7-300, was applied, that had been used for the control of the press and drying part of the machine. The capacity of the controller allows the expansion from existing 12 drives control and the same number of control boards to additional 16 drives and boards. Control board for each of the drive consists of one operational panel, Siemens OP7, which tasters are used for drive control, in the same manner as in the previous case.

It is mentioned, in the paper, that the tension force control is applied in some drives, or the load sharing control. Beside that, there are drives where the speed is regulated in the appropriate relation to reference speed. They are applicator rolls and guide ropes drives. In the case of drives where load sharing is utilized, the task is to keep it at the same percentage in relation to the rated motor torque of the prior drive. However, in the case of reel drive, the ability of additional torque increase at the reel drive is predicted, in relation to the prior drive, the drive of IX drying group, with the aim of better roll developing. Accordingly, there are five different control panels at the boards in the plant. The first is earlier described, and it posses only the basic functions, the operating regime choice, and the tension tuning, using the varying of reference speed correction in relation to speed of the prior drive, in the series. Block diagram of control algorithm and the record of characteristics screen are presented at fig. 5. This mode of control is established at the part of the drive where the web is wet and unformed, near to drying cylinder.

The second group of panels consists of drives with load sharing control, where the speed reference is permanently corrected depending on the torque difference between the prior and the observed drive, which is applied at the drives of VI-th, VII-th, and VIII-th drying group, calender and at all drives of guide roll. Figure 6 presents the operat-



**Figure 6. Block diagram and representation of characteristic screen for the second group panel (applied at the drives of VI-th, VII-th, and VIII-th drying group, calender and at all drives of guide roll)**

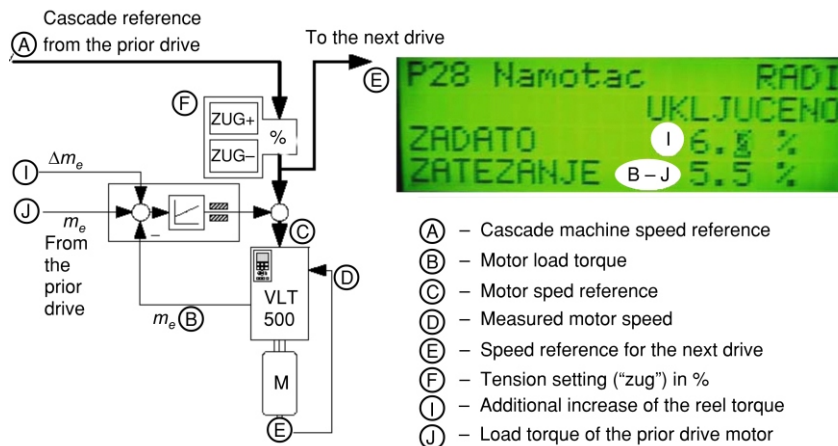


Figure 7. Block diagram and representation of characteristic screen for the third group panel – reel drive

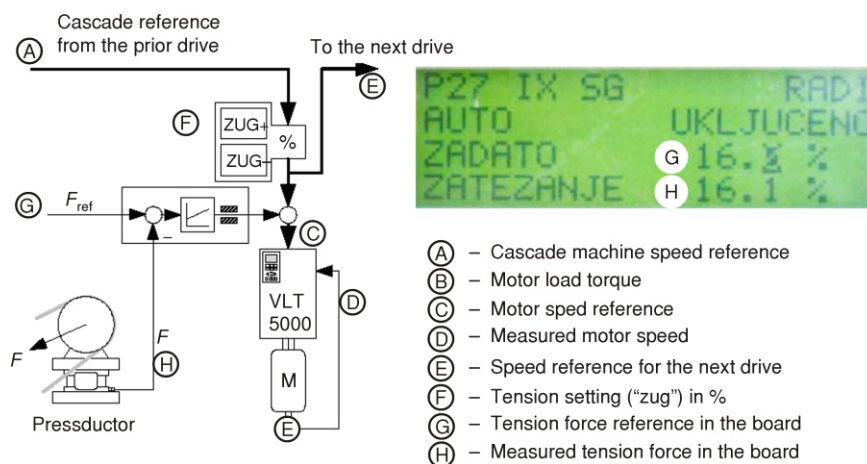
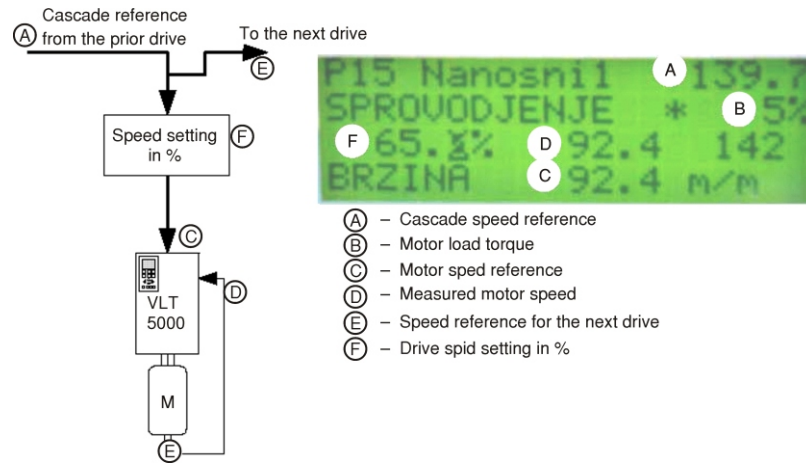


Figure 8. Block diagram and representation of characteristic screen for the fourth group panel (applied in the case of backing roll, drive of guide rolls V, and IX drying group)

ing principle, plus characteristics screen for this group of panels. The third group consists of panel for reel drive control, where the ability of tuning the load correlation between two drives is obtainable (fig. 7). The fourth group consists of panels for drawing drives control, where the tension force control is applied, on the basis of force measuring in a board, with the use of pressductor. This mode of operation is applied in the case of backing roll, drive of guide rolls V, and IX drying group. Figure 8 shows the block diagram of



**Figure 9. Block diagram and representation of characteristic screen for the fifth group panel – applicator rolls and guide ropes drive**

control algorithm and the record of characteristic screen. The value either of speed reference in a board, and of reel torque increase, can be directly entered as a numeral with the use of numerical tasters at the operating panel. The fifth group consists of panels for the control of applicator rolls and guide ropes drive control. They possess only one ability, to tune the speed on the desired proportion in correlation with the speed of the prior drive, fig. 9. This value of proportional decrease can be entered with the use of numerical tasters on the panel, too.

### Attained results

The reconstruction of press and drying part of the machine has been done within one larger activity on the board machine, in parallel with the extension of couch section, and new process computer introducing for technological control of process. All the activities have been finished within the predicted term, which lasted two weeks.

The equipment integrated in a new drive, takes many a time less place than the old drive. New motors can be seen at the fig. 10. On the left side, there is a group of three drive motors for three presses, and on the right side, there is a motor of one of drying groups. Energetic substation with all of 12 drives is located in one double cupboard together with the programmable controller, fig. 11 – left side. It should be mentioned that only thyristor rectifier for the drive motor of the line shaft was placed in this cupboard earlier, while the line shaft control was distributed into more than one cupboard. Converters are placed on free walls of electro hall, fig. 12 – right side. Figure 12 presents control panels in the plant.



**Figure 10. Drive motors of the new drive**

Within the period of exploitation, from the reconstruction, the new drive has operated quite successfully, practically, there were no break downs, or interruptions caused by recently built-in equipment. At the very beginning of exploitation some disturbances in operation of the new and the old DC drive at the crossing from drying group to coating part had occurred. More accurate, the web ripping was occurring at the first coating drive, the calender drive. Meanwhile, with the integration of described load sharing regulator between the last in the series of new drives, the drive of eight drying group, and the DC drive of calender, these problems were eliminated.

The drive reconstruction in the case of adding a plant for so called “third coating”, has been completed in parallel with actions in integration of equipment for preparing and coating a board. Thanks to well done preparation and organization, the job has been completed in the proposed period of three weeks. It should be underlined, that the part of the job concerning the drive has been performed by the team consisted of our people from investor’s company and Faculty within the desired period, while the other part of the job performed by the team from Germany and Austria, was delayed.

Within the period of exploitation, from the reconstruction, the new drive has operated quite successfully, practically, there were no break downs, or interruptions caused by recently built-in equipment. At the very beginning of exploitation it was noticed that the pair of old pressductors wasn’t properly operating. This manifestation causes the improper oper-



**Figure 11. Substation and control system (left side), converters (right side)**

**Figure 12. Control panels for press drives (left side) and one drying group (right side)**



ation of tension force regulators at the backing roll drive and guide roll V (drive number 9). That's why the load sharing regulation was applied in the case of the first backing roll drive instead of tension force regulation. The guide rolls drive V was removed after technological analyses of entire plant operation, because it was proved that it is not necessitated.

The equipment required for new drives, takes many a time less place than the old equipment, besides the fact, that the number of drives is nearly twice as much bigger than in the earlier case. Owing to new technology applied in the case of new frequency converters, the installation conditions and maintenance requirements are many a time smaller and simpler. Due to the lower price of induction motors, it was possible to avoid the use of forced cooling motors, that are more complicated for maintenance and much more expensive, with the choice of a little higher power motors. The fig.13 (left side) presents drives motor-gear boxes for driving of the board machine. Thus, locations of motor-gear boxes are chosen with the purpose of obtaining the direct coupling of gear-boxes ends with drive rolls, that requires earlier the use of cardan shaft. One of these cases is presented in fig. 13 (right side). Frequency converters are placed in the electro hall, while the existing cupboards and substation elements of the old thyristor plant are

**Figure 13. Driving motors of the new drive, directly coupled (left side), or across cardan shaft (right side)**





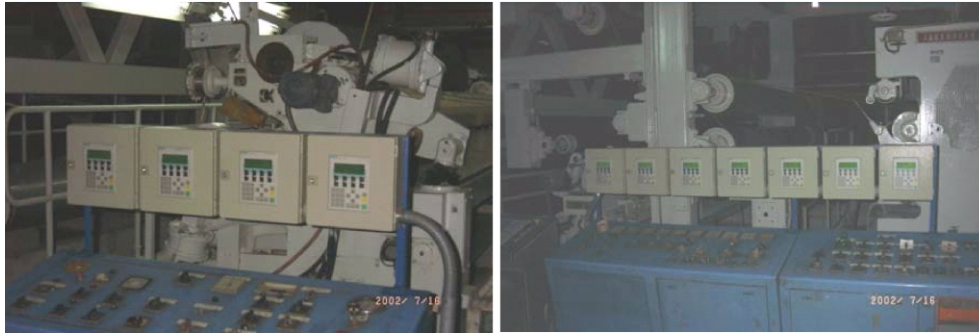


Figure 14. Control panels for the part of the drive

used for the distribution of supplying. Figure 14 presents control panels for sequential coating drives. The disposition of drives at the machine causes the panels grouping.

In accordance with all the facts presented above, it is obvious that the reconstructed drive represents the new concept of electrical drives based on energy efficiency principles. Results, which are shown in fig. 15, are obtained by measuring the power on separate parts of paper machine before and after reconstruction, for the same board weight. It can be clearly seen from the fig.15, that the main energy saving is attained at the drive of couch pump, for greater weights, *i. e.* lower web speeds, what is expected, owing to the mode of flow control at low speeds (closing of valves).

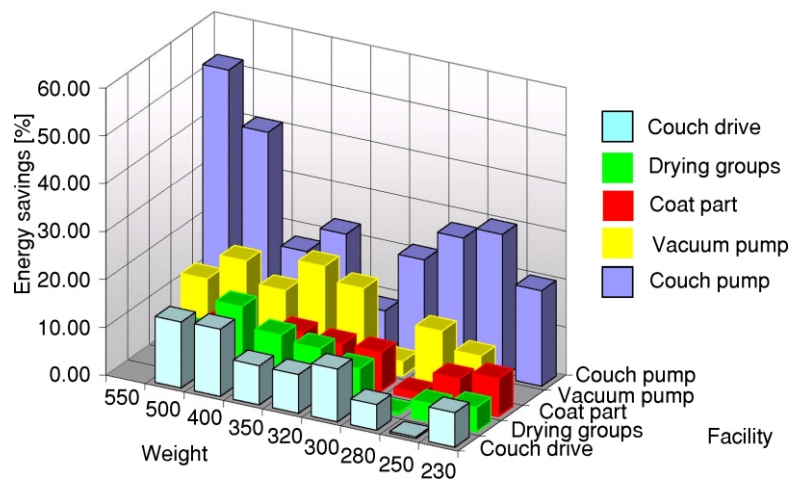


Figure15. Energy savings on different parts of paper machine

## Conclusions

The basic result of the drive reconstruction is the increase of the average speed of the board machine, and reduction of interruptions. That is confirmed with the fact that the production in the year after reconstruction was permanently over the planned one. The real maximal speed of the machine before reconstruction was 180 m/min., and after reconstruction the maximal speed in the amount of 300 m/min. is achieved. Further increase in the speed value is limited with the technological parameters of the machine, only. The investor had not any expense for maintenance of new equipment in the exploitation period of the drive, till now. The successful realization of this project, as well as previous similar results [4-6], confirm that the chosen concept of induction motor with frequency converter application is suitable, and obviously based on the energy efficiency principles.

The way of project realization, through adequate cooperation between investor's technical services, Laboratory for Electrical Drives of Faculty of Electrical Engineering in Belgrade, and the company Danfoss, as well as attained results, confirm the accuracy of this approach. The investments are significantly reduced, and through this way of realization, the investor's maintenance services are successfully trained in using and maintenance the novel technologies, that also reduces the costs of maintenance. It is necessary to bear in mind that the complexity and the high technological level of the applied equipment are fully in accordance with the trends in the industrial world.

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Authors' addresses:

*B. Jeftenić, M. Bebić, L. Ristić*

Faculty of Electrical Engineering, University of Belgrade,  
73, Bulevar Kralja Aleksandra, 11000 Belgrade, Serbia

*S. Štatkic*

Faculty of Electrical Engineering, University of Priština,  
7, Knjaza Miloša, 38220 Kosovska Mitrovica, Serbia

Corresponding author (B. Jeftenić):

E-mail: jeftenic@etf.bg.ac.yu

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