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TECHNO - ECONOMIC INDIKATORS OF SEAMLESS TUBE PRODUCTION

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First the paper presents a review of steel tubes production, especially seamless tubes. The tube production varied from about 74×10^6 tons down to 50×10^6 tons. This applies to seamless tubes (world ratio - welded tubes: seamless tubes was 70 : 30 %). Further in the article are presented the main characteristics of rolling stands for productions of seamless tubes and an analysis of techno - economic indicators. Development tendency at production of tubes as shown in tabular form.

Key words: *seamless tubes, techno - economics indicators, development tendency*

Tehno - ekonomski pokazatelji proizvodnje bešavnih cijevi. U članku je prvo dan pregled proizvodnje čeličnih cijevi, posebice bešavnih. Proizvodnja cijevi je varirala od cca 74×10^6 t do ispod 50×10^6 t. To se odnosi i na bešavne cijevi (odnos šavnih i bešavnih cijevi u svijetu je 70 : 30 %). U nastavku su date glavne karakteristike valjačkih stanova za proizvodnju bešavnih cijevi te analiza tehno - ekonomskih pokazatelja. Tabelarno su date razvojne tendencije u proizvodnji bešavnih cijevi.

Ključne riječi: *bešavne cijevi, tehno - ekonomski pokazatelji, tendencija razvoja*

INTRODUCTION

Great efforts have been recently made in the world of metallurgy in order to reduce raw material consumption and particularly energy consumption. Although most metallurgical products are produced by the proved procedures of plastic forming, some changes appear owing to the following requirements:

- improvement of product quality,
- reduction of production costs,
- increase of productivity as well as capacity, yield and equipment availability,
- higher flexibility concerning the production program.

The requirements for the quality parameters of hot and cold formed steel and non-ferrous metals increasingly insist upon [1 - 3]:

- optimisation of chemical composition,
- improvement of purity grade concerning the non-metal inclusions, oligo-elements and gas contents,
- restricted mechanical properties,
- more suitable and more uniform structure, less segregations,
- closer dimensional tolerances for: section, width, length, (wall thickness for pipes),
- improved straightness for flat products,
- section shape according to the forming procedure,
- improved surface quality (additional by grinding and polishing),
- surface treatment (coating by metals, plastics, varnish, etc.).

The ball bearing steel has to meet high requirements concerning the uniform carbide distribution, low inclusion and gas contents. High quality wires require high uniformity of chemical analysis, structure and mechanical properties as well as the superior surface quality, appropriate purity and a removable scale layer. For strand wires and springs of special strength an appropriate drawing possibility is required since they are first drawn up to the strength of 3000 MPa.

Cold-rolled strip for televisions masks, 0,15 mm thick, should have thickness tolerance below 4 μm with the best possible straightness and surface quality of 3 μm. Additionally, the restrictions of the carbon content up to 0,002 % as well as the size and distribution of inclusions are prescribed. Fine crystalline and amorphous thin strips have peculiar physical characteristics, e.g. the lowest losses expressed in W.

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Materials resistant to SCCC (Sulphide Stress Corrosion Cracks) have been developed for seamless pipes. In addition to the homogenized structure and mechanical properties (Cr-Mo-steel) high alloy steels with Ni and Cr and special stainless steels are used as well [3].

New grades of steel are used for seamless pipes. Grades up to X - 100 are used for line pipes. Materials resistant to brittleness caused by hydrogen (HIC - Hydrogen Induced Cracking) have also been produced. Low carbon steels (C $\leq$ 0,03%) are used for weldability improvement and the required properties are controlled by bainite structure. High alloy welded pipes (as austenite, ferrite) are necessary for specific purposes [4].

Intensive researches in the plastic forming theory and particularly in the process technology development are carried out in order to achieve these high requirements.

Nowadays, basic characteristics of world steel production and processing are specified through automation and processes management by means of computers. Actually, computer engineering and technology is a big and significant innovation in the recent years of metallurgy, the innovation being introduced with a great speed. In these days there are no single segment in up-to-date iron works without computers used for informing or processing managements. Production units or production lines without computers are considered to be out-of-date, because of small productivity, inefficiency and high costs. In developed countries, the computers participate with about 90 % in the managing of metallurgical processes in steel producing and working.

Therefore, the purpose of this article is to present a review of steel tubes production, especially seamless tubes, the characteristics of tubes, rolling stands and the techno - economic indicators of production.

REVIEW OF STEEL TUBES PRODUCTION

In 1970 steel tubes production amounted 7,7 % of world steel production. In 1980 world steel production was 717×10^6 tons, and tubes production was $70,3\times10^6$ tons, i.e. 9,8 %, and as early as in 1981 it increased to 10,8 % (steel - 707×10^6, and tubes $74,8\times10^6$ tons).

It means that the annual rate of increase of tubes production in those years was about 4 % unlike to previous predictions of 1,7 % for the same period.

The long-term prognoses from that time indicated to a possibility of a further increase of steel tubes production so as the annual increase rate be about 1 %. At a lower predicted increase of steel production the portion of tubes in the steel production would grow as far as 11 % (in 2000 an tube production over 80×10^6 tons per year is foreseen) [2].

These assumptions were not realised. Developed industrial countries, after the first and the second world oil crisis, underwent significant changes and restructuring in metallurgy. The fall of production in some countries was as much as 30 %.

The drop of tubes production was especially pronounced (in 1990 - $69,4\times10^6$ tons; in 1994 - 53×10^6 tons). This concerned the 6 most developed countries including the Commonwealth of Independent States (former USSR), which had nearly 90% of total world tube production. All kinds of tubes experienced then a drop of production level. Production drop of small diameter welded tubes reached 9 %. Large diameter welded tubes had a production drop for 14 %. The production of welded tubes dropped in total over 10 %.

Seamless tubes experienced a significant decrease of production (over 17 %). Then, the production amounted about 17×10^6 tons (1998 $15,1\times10^6$ tons).

Production of steel tubes in EU countries (European Union) decreased for 10 % in 1992. German producers did worst with a decrease of 16 %. Before all, the drop of production of seamless tubes (25 %) is to blame for such a development. The production of the seamless tubes decreased to the level of 1,2 mil. tons. In Germany, the production of welded tubes was 2,4 mil. tons in comparison with 2,7 mil. tons in the previous year (minus 11 %). The production of small diameter welded tubes decreased only for 9 % to 1,4 mil. tons. However big diameter welded tubes experienced a drop for 14 %, i.e. to 1 mil. tons.

Another strong drop of production happened in Eastern Europe. In it, the production reduced for 3,8 mil. tons, i.e. to 16,2 mil. tons. The Commonwealth of Independent States, as a main producer of this group of countries, produced only 13 mil. tons. In 1988, the USSR then produced more than 26,3 mil. tons [4].

In USA, the production declined for 7 %, which is below the average. It is mainly due to the increase for 11 % of the production of smal1 diameter welded tubes.

A significant minus can be noticed in the production of big diameter tubes, because their production decreased nearly for a half. However, the production in general was over the average because of great orders in the sector of energy production.

Very difficult situation in the whole world market of steel tubes affected also Japanese tube producers, where the problems of the local market are also to be added. This is why there, in spite of a partially great export (e.g. in China), the production fell for 13 %, which is little more than the world average. At the big diameter tubes, the production decrease is comparatively small (minus 4 %). On the contrary, the production of seamless tubes is smaller for a quarter, a large excess of production capacity continues to be noticeable in the whole world [6]. This crisis is overcome, so the production increases again, especially steel production. As early as in 2002, there were produced 804×10^6 tons of steel, and in 2002 it amounted 848×10^6 tons and in 2003 $\approx 940\times10^6$ tons (the production in developed countries in converters and electric arc processes in a ratio 3:1).

As for Croatia, it is well known, that steel production in former Yugoslavia amounted about 4.500.000,00 tons, in which Croatia participated with 500.000,00 tons [7].

Before the war (according to the information for 1989), Croatia participated in steel production with about 20 %, which means that it experienced a drop of steel production in the framework of the former state. The difference was covered by importing, or supplying from the market of the former state.

In the former state, Croatia was the only producer of seamless tubes among 34 world countries - Željezara Sisak, Sisak, and also a remarkable producer of welded tubes (Željezara Sisak - Sisak and Histria Tube, Potpićan).

For instance: in 1989, the production of seamless tubes (relates only to the 1. quality tubes) was as much as 138000 tons, and welded tubes 184000 tons.

Because of the war conditions, a remarkable drop of its own steel production, loss of its market, like other steel producers in the world, the production decreased no less than 70 %. Although in 1995 the production of seamless tubes amounted 12.000,00 tons and welded tubes 72.000,00 tons, in 2002 and 2003 (seamless tubes 22.472 and 25.319; welded tubes 12.715 and 37.503 tons).

The welded rolling mill in Potpićan has an annual output of about 12.000,00 tons, which is completely put in use.

Table 1. **EU steel tube industry: all tubes**
Tablica 1. **EZ - čelične cijevi: sve cijevi**

States	2001		2002	
	1000 t	%	1000 t	%
Tube Production there of	13.513,5	100,00	13.145,9	100,00
Germany	3.491,1	25,89	3.288,5	25,02
Italy	3.414,1	25,32	3.296,9	25,08
France	1.629,6	12,09	1.499,9	11,41
Belgium	209,3	1,55	197,9	1,51
Netherlands	424,7	3,15	444,6	3,38
Luxembourg	76,3	0,56	13,0	0,10
United Kingdom	1.084,8	8,09	1.108,1	8,43
Denmark	114,7	0,88	130,3	0,99
Ireland	7,6	0,06	7,6	0,08
Greece	488,1	3,52	561,8	4,27
Spain	1.256,8	8,03	1.305,1	10,27
Portugal	100,0	0,74	100,0	0,76
Sweden	210,5	1,56	202,9	1,64
Finland	426,0	3,16	427,3	3,25
Austria	581,9	4,32	517,0	3,93

Very interesting is EU structure of steel tube industry: Table 1. - for all tubes, Table 2. - for seamless tubes.

Table 2. **EU steel tube industry: seamless tubes**
Tablica 2. **EZ - čelične cijevi: bešavne cijevi**

States	2001		2002	
	1000 t	%	1000 t	%
Tube Production there of	3.706,0	100,00	3.334,5	100,00
Germany	1.439,6	39,20	1.316,8	39,48
Italy	776,6	21,20	665,2	20,55
France	881,0	18,54	605,0	18,14
Belgium	-	-	-	-
Netherlands	14,2	-	12,7	-
Luxembourg	-	-	-	-
United Kingdom	62,0	1,85	53,7	1,61
Denmark	-	-	-	-
Ireland	-	-	-	-
Greece	-	-	-	-
Spain	277,5	6,51	269,7	8,09
Portugal	-	-	-	-
Sweden	101,9	2,77	69,0	2,86
Finland	-	-	-	-
Austria	365,2	9,94	309,1	9,27

Table 3. gives the whole production of steel for 2002, ratio (%) of the whole tubes production for each state and ratio (%) of seamless tubes production.

Table 3. **Production of steel, ratio (%) of all tubes production, and ratio (%) of seamless tubes**
Tablica 3. **Proizvodnja čelika, udio (%) proizvodnje svih cijevi i udio (%) bešavnih cijevi**

States	2002 Steel / $\times 10^6$ t	All tubes production %	Seamless tubes production %
Germany	45,0	7,30	2,92
Italy	25,9	12,72	2,64
France	20,5	7,31	2,95
Belgium	11,4	1,73	-
Netherlands	6,1	7,28	0,20
Luxembourg	2,7	0,004	-
United Kingdom	11,7	9,47	0,45
Spain	16,3	8,28	1,65
Sweden	5,8	3,49	1,65
Finland	4,0	10,68	-
Austria	6,2	8,33	4,98

The whole production of steel in the states (Table 3.) was $155{,}6\times10^6$ tons and the production of all tubes was $12{,}34\times10^6$ tons, i.e. ratio 7,93 %. Total ratio - welded tubes: seamless tubes in EU was 74,64 : 25,36 %.

TECHNO - ECONOMIC INDICATORS

The process of production of seamless tubes and type rolling mill installations is characterized by an expedient expansion of a tube (obtained by weaving or moulding) in a tube. The operation of an expansion institutes a sort, productivity, final quality level of commodity and production efficiency [7, 8].

Tube rolling mill installations with automatical , pilger, continuous mill and three-roll reeling (Assel) mills for production of hot-rolled seamless tubes have received the greatest distribution in a world. These installations differ on the technological indices (Table 4.).

Table 4. **Performance of seamless tube mill**
Tablica 4. **Karakteristike valjaonica za bešavne cijevi**

Indexes	The type reeling mill			
	auto-matical	conti-nuous mill	pilger	three-roll reeling (Assel)
Sort: - diameter of rolled tubes / mm - a ratio D/S	57 - 426 4,45	30 - 102 10 - 13	22 - 700 6 - 40	34 - 200 4,12
Supposed aberrations: / % - on diameter - on wall thickness	± 1 ± 12,5	± 1 ± 12,5	± 1 ± 12,5	± 0,5 ± 6,0
Productivity, thousand tonn annually	70 - 340	110 - 600	190 - 340	22 - 230
Account coefficient	1,08 - 1,14	1,075 - 1,090	1,193 - 1,227	1,175 - 1,257
Share of time in rhythm of rolling: - engine % - supplementary % - unsteady stages %	20 - 25 80 - 75 1	50 - 60 50 - 40 1	75 - 80 25 - 20 15 - 18	80 - 85 20 - 15 2 - 3
Coefficient of an extract: - at weaving - at an expansion	1,3 - 5,2 1,2 - 2,1	1,8 - 3,0 3,0 - 6,5	1,3 - 2,1 3,0 - 15	1,3 - 2,1 1,8 - 3,2

The installations with automatical and pilger mill have the broadest sort. The installations with continuous and three-roll reeling mill are applied to production of small and angle diameter tubes, the first - for rather thin-wall, and the second - for heavy-wall tubes [9].

The modern installations with continuous mill (mandrel mill) have top performances. Seamless tube rolling mill installation with three-roll reeling mill ensures deriving tubes in a split-hair accuracy, in 1,5 to 2,0 times superior an exactitude of tube than on other installations.

Allowing, that the expenditures on metallurgical process on all seamless tube rolling mill installations compound 15 to 40 % from product cost, and 60 to 85 % are necessary for the cost of metal, the major value is acquired by (with) such an index, as account coefficient, which is the greatest on installations with pilger (in connection with availability pilger head) and three-roll (considerable end pop and necessity a turning of tubes) reeling mill.

Besides seamless tube rolling mill installations with pilger and three-roll reeling mill at the least share of a dead time in rhythm of rolling the continuous unsteady stages of process of an expansion have.

The analysis of technological indices of production of tubes on different seamless tube rolling installations allows defining reference directions of improving of the “know-how“ of tubes encompassing by following:

- heightening of an exactness of tubes on installations with self-acting. mandrel and pilger mill,
- expansion of a sort of installations with three-roll reeling mill and heightening of their productivity,
- decrease of account coefficient on installations with pilger and three-roll mill,
- abatement of a dead time in rhythm of rolling on automatical and continuous mill,
- abatement of time of unsteady stages of processes of an expansion on pilger and three-roll mill.

At a solution of the question about perfecting production it is very important to have an opportunity to institute influencing technology, design and organization - engineering measures on a production efficiency. It will allow selecting for introducing those measures, which can most contribute a production efficiency.

Table 5. **Change of indices by production hot rolling of seamless tube**
Tablica 5. **Promjena parametara pri proizvodnji toplo valjanih bešavnih cijevi**

Indexes	Including:			
	All	Opening-up of performs	a strain (defor-mation)	finish
Losses of metal at production of tubes %	5 - 60	1 - 25	2 - 10	2 - 30
Capital of an expenditure / %	100	2 - 15	20 - 70	25 - 50
The cost 1 hour of operation of installations / %	100	2 - 15	30 - 70	15 - 60
Annual working time fund of installations /hour		7500 - 8100	6500 - 7500	7500 - 8100
Annual working time fund of installations /hour		100 - 800	1000 - 25000	1000 - 25000

For complex examination of process of deriving hot-rolled of tubes irrespective of an expedient of a strain and used inventory the universal mathematical model of production linking technological parameters of process, design features of installations, performance of performing process and ready tubes with measure of an estimation of an economic efficiency is created.

Generalized measures of estimation of an economic efficiency of production are the reduced expenditures (Z), representing the total of the carrying costs (cost price) and capital investments, reduced to identical dimensionality according to normative effective ratio and definiendum from expression

$$Z = S_m + S_p + E_h K \quad (1)$$

where:

S_m - expenditure on metal;
S_p - expenditures on metallurgical process;
E_h - normative effectiveness ratio of capital investments;
K - investment costs.

Having substituted in the formula (1) values of devices of reduced expenditures expressed through parameters describing guideline (opening-up of performs, deformation and finish) production of hot-rolled tubes, after transformations we shall receive

$$Z = l_g \left\{ q_g \left[\alpha_\Sigma S_z - S_{otx} \left(\alpha_\Sigma - 1 \right) \right] + \right. \\ + \alpha_\Sigma \left[\left(\frac{B_{pz}}{P_{pz}\mu} + \frac{B_d}{P_d \alpha_{pz}} + \frac{B_{otd}}{P_{otd}\alpha_{pz}\alpha_d} \right) + \right. \\ \left. \left. + E_h \left(\frac{K_{pz}}{P_{pz}T_{rpz}\mu} + \frac{K_d}{P_d T_{rd}\alpha_{pz}} + \frac{K_{otd}}{P_{otd}T_{rotd}\alpha_{pz}\alpha_d} \right) \right] \right\} \quad (2)$$

where:

l_g - annual volume of production, m;
q_g - mass 1 m of ready tubes;
α_Σ, α_{pz}, α_d - account coefficient of metal (aggregate, at opening-up of performs and at a hot strain);
S_z, S_{otx} - cost of performs and wastes, rbl/t (or $/t);
B_{pz}, B_d, B_{otd} - cost of one operating hours of inventory at opening-up of performs, strain and finish of tubes, rbl/hour (or $/t);
P_{pz}, P_d, P_{otd} - productivity of leases of opening-up of performs, hot strain and finish, m/hour;

Table 6. **Development tendency at production of seamless tubes**
Tablica 6. **Razvojne tendencije u proizvodnji bešavnih cijevi**

CHARGE	ROLLING	FINISHING, COLD FORMING, HEAT TREATMENT
Continuous casting of round sections Continuous cast hollow shell The charge with the improved possibility for hot and cold forming and superior surface quality Application of centrifugal cast raw pipes and high alloy steel pipes	PPM (Press piercing mill) - pressure rolling mill for longitudinal charge piercing MPM (Multi stand pipe mill) - continuous mill with the mandrel retention device - Ital. variant MPM-SL (Multi standless pipe mill) - continuous mill (without stands) with the common housing and a mandrel retention device - Ital. variant NEUVAL process - French variant of MPM with the retained mandrel by which a tube blank was previously - pierced at the cross rolling stand MPM - Aetna Standard Co. - Continuous rolling mill with a free, half-retained and retained mandrel, example: “VBC SUMITOMO” MRK-S (Mannesmann Rohrkontiwalzwerk mit Striperverfahren) - Mannesmann-variant of MRK with a stripper and half-retained mandrel MRK-AR (Mannesmann Rohrkontiwalzwerk mit Ausziehrohrwalzwerk) - Mannesmann-variant of MRK with a mandrel-retention device with a drawing stand CPE (Crossroll picrcing elongation) - piercing by cross rolling with an elongation at the push bench CPD (Crossroll piercing Diescher elongationl - piercing by cross rolling with an elongation at the Diescher stand with the mandrel retention ACCU-ROOL (Procedure similar to CPD) - piercing by cross rolling with an elongation at the cross rolling stand by Diescher's discs with the retained mandrel, developed by Aetna Standard Co. in 4 versions PSW (Planeten - Schrägwalzerk) - planetary cross rolling stand for pipes	Development of non-destructive testing procedures High-efficiency devices for development Plastic coating, internal grinding Continuous cold rolling of pipes Application of multi-drawings resp. tandem- and multiple cold and pilger machines High-efficiency cold pilger stands

μ - coefficient of an extract;

K_{pz}, K_d, K_{otd} - investment costs on a building of leases of opening-up of performing process, strain and finish of tubes, rbl. (or $);

T_{rpz}, T_{rd}, T_{rotd} - annual working time fund at opening-up of performing process, hot strain and finish of tubes, hour.

If necessary of in-depth analysis probably more detail division of production into leases.

Knowing values of magnitudes which are included in expression (2), and also the change is possible to investigate them depending on spent measures on improving production of tubes by miscellaneous expedients, influencing miscellaneous factors on a production efficiency and, as a corollary to define directions of his improving to provide the greatest efficiency. The obtained expression allows to determine the size of reduced expenditures by production of tubes of concrete aspects and sizes made by miscellaneous expedients of hot strain, and, therefore, to select the most expedient of production of tubes of each concrete aspect and size.

For confrontation it is possible to utilize magnitude of specific reduced expenditures defined of expression:

$$Z_{ud} = \frac{Z}{l_g} \tag{3}$$

The analysis of features of production of hot rolling tubes by miscellaneous expedients displays, that the basic magnitudes varying at improving of production and included in expressions (2) and (3), oscillate in considerable limits (Table 5.).

The calculations under the formula (2) display, that the abbreviation of expenditure of metal allows considerably increasing production efficiency, and at an identical decrease of account coefficient the efficiency rises to the greatest degree at an abatement of waste metals on finishing operations. From here it is possible to make a practical output about necessity of careful opening-up of performing operations with a heightening of expenditure of metal on this production phase under condition of the relevant decrease of account coefficient on consequent operations.

The improving of other separate parameters does not give such a considerable increase in the effectiveness of production, as a decrease of account coefficients of metal. The elimination is compounded by (with) operations having a major specific gravity in reduced expenditures or being “narrow” places in production process, first of all, processes of expansion.

INSTEAD OF CONCLUSION

Besides the review of the world tube production (from 10 % to 6 % of steel production) a review of the decrease of world seamless tubes production is also presented with designated free capacities. The characteristics of rolling mill plants are also illustrated. The largest item in this presentation is material item (60 % to 85 %). More detailed is elaborated the criterion of evaluation of economic efficiency with influencing factors against the universal mathematical model of production. A great attention is given to the improving of the existing technologies of seamless tubes production.

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