II

Modern Methods of Fabrication and Automatization of In-line Production of Metal Structural Members

Procédés modernes de fabrication et production automatisée des structures métalliques

Moderne Herstellungsverfahren und Automatisierung der Fliessfertigung von Stahlkonstruktionen

N.P. MELNIKOV
Dr. Sc., Prof., Corresp. Member, Academy of Sciences of the USSR
TSNIIPROEKTSTALKONSTRUCTSIYA
Moscow, USSR

SUMMARY
The report considers modern fabrication methods for metal structural members and presents development trends based on a new progressive technology with a complex mechanization and automatization of production.

Main tendencies of further technological progress in the fabrication of metal structural members are determined and principles for an accelerated transition from individual and small-scale production to large-scale and mass-production of metal structural members are presented.

RESUME
Le rapport présente les méthodes modernes de fabrication d'éléments de charpentes métalliques et considère les tendances de développement qui dépendent d'une technologie progressive comportant une mécanisation complexe et une automatisation de la production.

On établit les directions principales du progrès technique à venir dans le domaine de la production des charpentes métalliques et on expose les principes permettant une passage rapide de la production individuelle ou en petite série à la production en masse ou en grande série.

ZUSAMMENFASSUNG
Es werden moderne Herstellungsverfahren für Stahlbauelemente dargestellt und deren Entwicklungstendenzen auf der Grundlage einer progressiven Technologie mit komplexer Mechanisierung und Automatisierung der Fertigung betrachtet.

Die Hauptrichtungen des weiteren technischen Fortschrittes in der Produktion von Stahlbauelementen werden aufgezeigt und Prinzipien eines schnelleren Überganges von der Einzel- und Kleinserienfertigung zur Grossserien- und Massenproduktion im Metallbau formuliert.

New achievements in science and technology are a basis for the development of metal structural members both in the Soviet Union and abroad. These achievements take three main routes:

- development of constructional forms theory directed at increased effectiveness, greater safety and longer service life;
- development of the theory of technological processes of inplant structural member fabrication based on new automated and mechanized methods of production;
- development of new in-line large block assembly technique, raising the level of mechanization and improvement of organization of various processes.

These three directions are regarded as a whole determining optimal effectiveness of forms of structural members and methods of their fabrication and assemblage.

World metal member fabrication has become intensified and by the end of the 20th century overall production may be 30 million tons per year, including over 15 mln tons in the Soviet Union.

This is the reason why during the past few years in many countries great attention has been paid to the development of the theory of technological in-plant metal member fabrication processes together with problems of the constructional forms improving.

The theory of technological in-plant metal structural member fabrication processes considers the solving of problems connected with basic production operations of machining, assembling, welding, finishing and ways of their intensification. It considers also the problems of creating an industry of metal structural members: the selection of the type and capacity of the plants and determination of metal structures volumes production in the country, specialization and plants rational dislocation over the country territory. As far as pure technology is concerned, the technological processes theory includes the development of the following problems: main principles of in-line production development (forming of principles of the automatization and mechanization of fabrication; machinery and equipment for in-line production); technological process peculiarities in fabricating structural members of high-strength steel, special corrosion protection techniques in in-line production; methods of intensifying production of structural elements, principles of scientific organization of labour and management in flow chart fabrication on all production lines.

Today, the first and foremost aspect of the technical revolution is automatization and application of computers in production processes. The revolutionary upheaval in automatization is conditioned above all by the creation of reflector-type systems controlling the technological process of fabrication according to a pre-set programme.

The conventional three-unit machine complex (engine-transfer unit-processing equipment) is enlarged and to it a fourth and a fifth unit are added - an automatic device and the computer.

The application of computers will bring into being new possibilities in the development of automated equipment and will make possible a sharp increase in effectiveness of metal structures fabrication.

Complex automatization leaves it to machinery and equipment to perform the five main and auxiliary functions of the working process: technology, transportation, energy problem, control and measuring, logics.

Constructional forms of the products and methods of their in-line production are regarded as a whole. The basic requirements that the constructional form should meet consist in the following: structural members should be easily divided into gradually enlarged assembly units; overall dimensions of enlarged members should not hamper handling of members on production lines; the number of type-sizes should be minimal.

Thus, automatization and mechanization of structural member fabrication processes is closely bound with problems of developing the necessary constructional forms. Analysis shows that most structural members for industrial buildings can be fabricated using up-to-date production techniques already at present. In the future, new methods of production will be evidently used for the fabrication of structural members of a wider range. The application of new mechanized and automated production processes and the creation of constructional forms in keeping with these processes open up new possibilities in the development of industrialized structural engineering.

The introduction of a new fabrication technology requires the development of typical metal structural members of mass application which fully meet the requirements of their in-line production. Plants producing metal structures should be equipped with flow lines for the fabrication of typical structures.

Small series metal member production has a low coefficient of the machinery working time usage (in metal machining shops - from 0.1 to 0.3) and a low level of mechanization of auxiliary processes: the mechanization factor approximately amounts to 0.25 - 0.45 (Fig. 1). A most important problem of increasing the mechanization level is brought into being. An analysis of the problem of labour spent per each ton of metal structural members produced shows that during the last decade the decrease of labour expenditure per ton of metal structurals has considerably lowered.

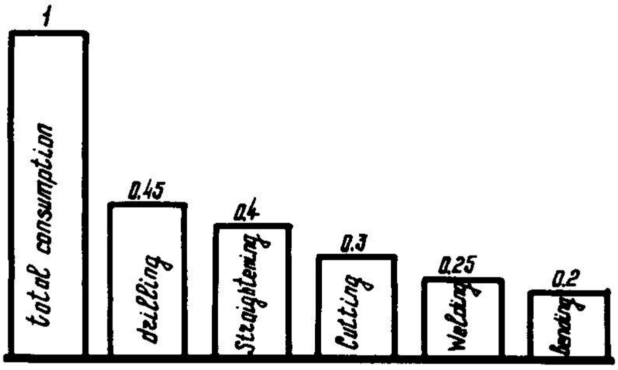

Fig. 1. Mechanization coefficient for small-series production.

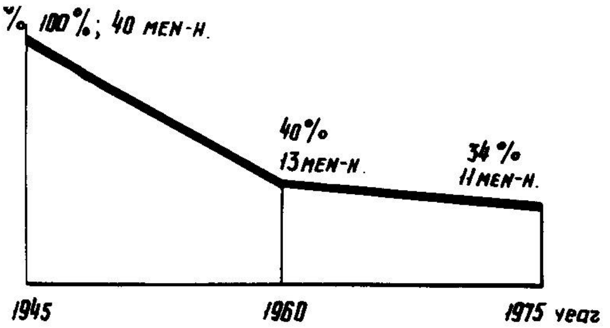

Fig. 2. Change in labour consumption per ton of metal structural members during the period 1945-1976.

In the 1946-1961 period labour expenditure decreased from 40 men/hours (1946) to 14 men/hours (1961), i.e. 2.5 times, while in the 1961-1975 period this decrease amounted only to 15 per cent. To a certain extent this is accounted for by the single unit and small series character of production.

The technical and economic data given in Fig. 2 show that further possibilities of intensification of single unit and small series metal member production are being spent up.

In the past, labour consumption was cut by using simple structures, substituting riveting for welding, machine cutting for gas cutting, introduction of modern equipment for processing, assemblage and welding and finishing, application of lateral movement of the cranes at all stages of the production process. The metal is moved in the longitudinal direction by means of the ground handling equipment. The transverse movement of the material is effected through the application of bridge cranes, a wide range of special devices such as automated desks, jigs, tilters, etc. used with metal-working machinery. All this made it possible to cut labour consumption but the single unit and small series methods of production do not allow a further considerable increase of the productivity of labour. An important reason for low productivity of labour are frequent breaks in the service of the equipment due to a great number of auxiliary manual operations. It follows that the most important problem is automatization of all production operations and, above all, ancillary ones. In this case a great disproportion exists between the main and auxiliary operations of the working cycle. At working steel structures production facilities it can be partially solved by the introduction of manipulators, mechanization of transport facilities ensuring successive transfer of elements from one to the next operator's position.

The solving of this problem is undoubtedly necessary but it is by far not the only one. A cardinal solution should comprize the application of automated machine-tools for the machining of metal, which perform all the auxiliary operations without man's interference, machining processes are pre-set by means of a special programme and control systems ensure the accuracy of operations.

An important condition for the reduction of the machining cycle is also the introduction a direct-flow technological layout with respect to the movement of members which are being machined.

The introduction of all-round mechanization of all technological process operations brings about a new industrial technology based upon the use of mechanized and automated flow lines allowing the in-line fabrication of structural members.

The experience gained from the application of flow-lines introduced in this country and abroad during the past 15 years in machining shops of a number of plants permits to make a positive evaluation of the flow-line production method. This experience is also ample proof of the fact that unless the fabrication process is automatized we cannot expect high productivity rates.

The development of new types of equipment, particularly of the flow-line type, requires a long period of time and collective efforts of experts in many countries. Therefore an all-round discussion of flow-line production problem is necessary at our symposium; we must collectively work out solutions directed at a speedy development of automatization and mechanization of the metal member fabrication process to be regarded as the main direction of development in the fabrication of metal structural members.

The theory of the industrial fabrication technology regards the main aspects of industrial operations: storing, trimming, machining, assemblage, welding, and corrosion protection of structural elements.

The principal method of connection is arc welding. Resistance welding and other welding processes also find application in this field.

The application of new and more effective methods of structural member machining as compared to the conventional ones brings forth the task of transforming production on the basis of automatization. Intensification of fabrication processes of structural members envisages the transition to a narrower specialization. In this connection an analysis of production volumes and structure of industrial fabrication becomes necessary. A transition to new production methods requires determination of price-formation laws for metal structural members, an analysis of labour consumption and cost laws.

On the basis of the experience gained in the service of flow-line production in general engineering it can be considered that there may be two types of flow lines.

The first type of lines are multi-item grouped flow-lines for the fabrication of members of several denominations using one common technological process. Members to be fabricated using these lines are selected in batches machined using the same equipment and technological process. Fig. 3 shows such a flow line for machining metal members. Flow lines for machining metal, specialized according to the type of the shapes are positioned as a chain of machine-tools and operator's positions located in a direct-flow way and interconnected due to consecutiveness of operations. Each set of equipment is responsible for a separate member. The lines are made up of special and universal machine-tools put out by the industry and equipped with manipulators and similar devices with servocontrol which automatize the machine-tools operation and take care of all auxiliary processes connected with machining (such as delivery of members, their orientation, starting of the machine-tools, removal of machined members from the machine-tool, etc.).

Application of manipulators considerably improves the level of automatization of the production operations throughout the entire line.

An important advantage of flow-line machining is a considerable cutting down of the number of bridge cranes since machined members will be moved using roller conveyers, transporters and other ground based material handling equipment. The cranes are left mainly for the maintenance and installation of the equipment.

The second type constitutes grouped single-item flow lines for assemblage of structural members which include all operations for assembling, welding, and making erection joints in fabricated members.

As opposed to flow lines for machining metal members assemblage lines are specialized according to types of structures which should have constructive and technological uniformity (Fig. 4). It should be noted that a successful flow-line assemblage-and-welding technique depends on the level of combined unification of the constructional form and the technological process. Thus, the constructional form is required to meet a new and very

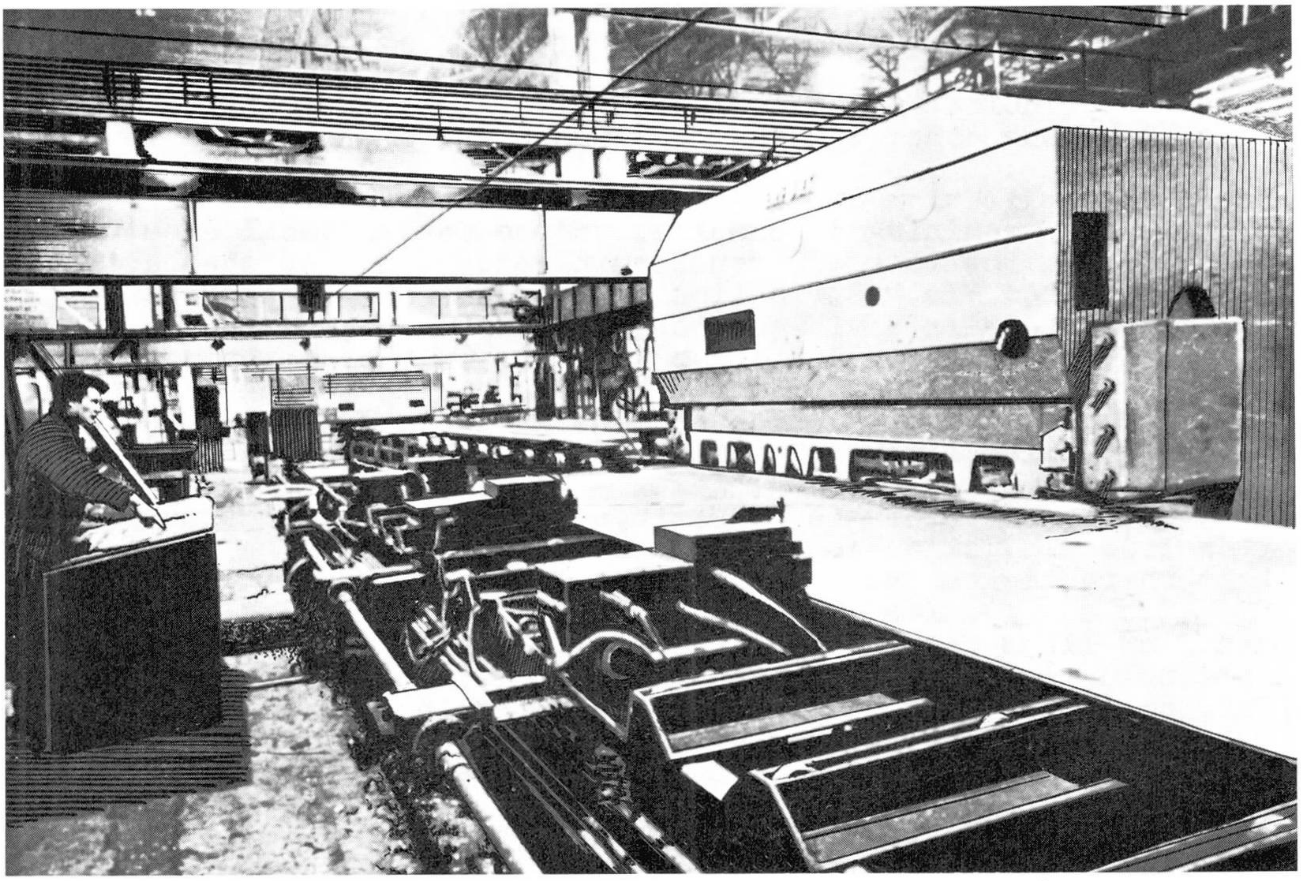

Fig. 3. General view of sheet-steel rolled shapes processing line.

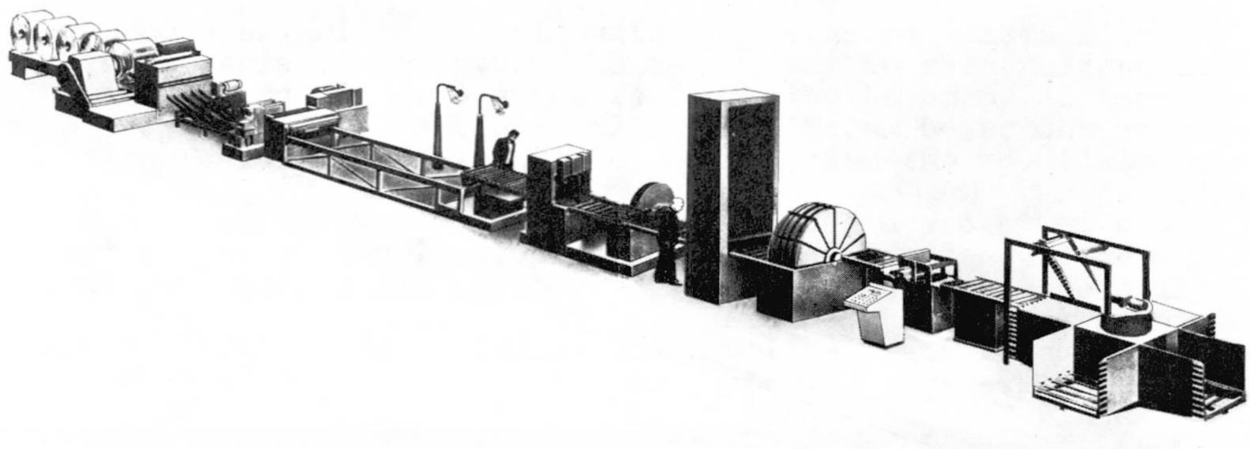

Fig. 4. General view of latticed platforms fabrication line.

important condition - it should correspond to the flow-line production process. A peculiar feature of grouped single item flow lines consists in the fact that all of them are capable of being re-adjusted and fitted for technologically uniform structural members which are grouped in batches. There should be no basic differences between batches. Allowable divergencies include different thicknesses of members, rolled shape sizes, number of assembly members and the like.

Assemblage is done in batches by means of gradual enlargement. All the sections of the assemblage flow lines are interconnected by transport facilities.

Research shows that, depending on the type of the product, several kinds of flow-line production may exist.

In fabricating one type of structural member, such as purlins, trusses and girders, etc., it is possible to concentrate all operations in one highly mechanized complex (set of machinery), including infeed of members being assembled, their positioning, clamping, securing and welding. This is the way it is done, for instance, in the "Butler" firm plants in the USA.

While preparing a set of structural members for assemblage of a structure flow lines may consist of several sets of machinery.

All sections of the assemblage flow lines are interconnected by transport facilities. This type of flow-line production requires an efficient interconnection between the flow-line and the machining shop which prepares structural members for all structures put out by assemblage-and-welding flow-lines.

During the past few years in different countries investigations have been carried out of the problem of assemblage and welding of steel structural members of mass application using highly mechanized flow lines for assemblage and welding of structures.

As a result of investigations carried out in our country the following principles may be recommended as the basis of the technological process of steel building structures fabrication by inline production methods:

- all components are to be processed in the shop on flow lines furnished with specialized equipment according to the type of rolled steel;
- structures assembly and welding operations are to be carried out in the assembly shop on specialized flow lines according to the type of structures;
- painting of the finished product is to be carried out in the shop on flow lines intended for several types of similar structures.

In order to reduce labour consumption and to cut down the time required for assembly and welding operations flow lines should be provided with highly mechanized assembly jigs under automatic control, which may perform a number of operations.

Assembly of structures should be performed without tacking of the components to be fitted in the mechanized assembly jigs. The assembled structure should be welded in the same jig in which it had been assembled. Such operations as hand fitting of components, deburring and hand straightening of the whole structure and its components are completely avoided. The movement of the components of the structure to be assembled through the line in the main direction of loads transfer - from the pre-fabricated products store to the painting shop - is to be accomplished by adequate provision of surface transport, i.e. roller equipped tables, conveyers, etc.

In the Soviet Union the following design capacities of flow lines for large plants have been established by the works of design institutes TSNIIPROEKTSTALKONSTRUCTSIYA, VISP and PROMSTALKONSTRUCTSIA (see table I):

Table 1

Flow line designation	Design capacity per year, thou. t	Firm
For processing of:		
Large plates, including the zone of welded I-beams fabrication	36	TSNIIPSK and VISP
small plate components	40	TSNIIPSK
made of angles components	13.5	PROMSTALKONSTRUCTSIA
beam and channel components	25	PROMSTALKONSTRUCTSIA
For assembly and welding of the following structures:		
two-branch columns	20	TSNIIPSK and VISP
roof-trusses made of angles	25	TSNIIPSK
roof-trusses made of tubes	20	VISP
crane girders	18	TSNIIPSK and VISP
lattice purlins	6	TSNIIPSK and VISP
sashes for monitors	3.2	VISP
side beams for monitors	7	TSNIIPSK and VISP
monitor panels	3.2	TSNIIPSK and VISP
monitor trusses	6	TSNIIPSK and VISP

The flow line for two-branch columns fabrication consists of three zones (see Fig. 5): the zone of total assembly, tack welding and partial welding of columns (I); the zone of distribution (II) and the zone of columns final assembly and welding (III).

The operation procedure is as follows: At first the stock feed racks of the flow line are loaded with column components. Diagonals, posts, membranes, caps are moved by means of electric trolleys 1 from the processing shop and an overhead bridge crane loads these components on to stock feed racks 3. The two branches of the column are simultaneously advanced by roller conveyors 4 to the first zone of the line up to the end stops. The components of the columns (membranes, lattices, etc.) are transferred by trucks moving along platform 5 from feed racks to manipulators 6 of the assembly jigs. The components are fixed in the position required and the trucks are removed.

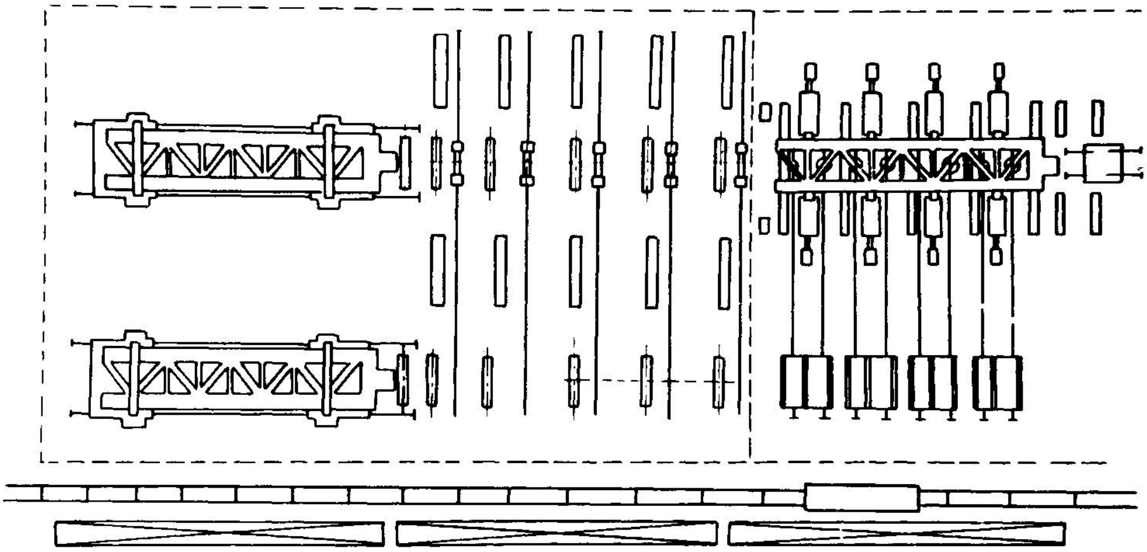

Fig. 5. Lay-out of flow line for fabrication of two-branch columns.

After that the branches of the column are rotated by structural shape rotators for the location of the lattice members. Then the operator using special device 8 advances a crane cross-member up to the ends of the column branches. The diagonals and posts are inserted to the branch flanges by the manipulators 6. The assembly is over and tacking and partial welding operations are to be performed.

The assembled and partially welded column is moved by means of roller conveyers 9 and a system of cable trolleys 10 through the distribution zone II to rotor tilters 11. The column base assembly and final welding is carried out in tilting jigs. The finished column is moved to the painting shop.

Technical-and-economic characteristics of the flow line for two-branch columns assembly and welding are as follows:

Output, thou. t/year.	24
The zone area, sq m	1728
Number of workers (two-shifts work), men	26
Output per 1 sq m of the production area, t/year	13.9
Annual production per worker, t	923

The flow line for assembly and welding of roof trusses made of angles with parallel chords spanned 18, 24, 30 and 26 m is shown in Fig. 6. The line performs under automatic control assembly and welding of diagonals and posts, assembly and welding of chords, total assembly of the trusses. The principle of a gradual enlargement of the members is used in the flow line operation.

The components of the posts and diagonals are advanced from

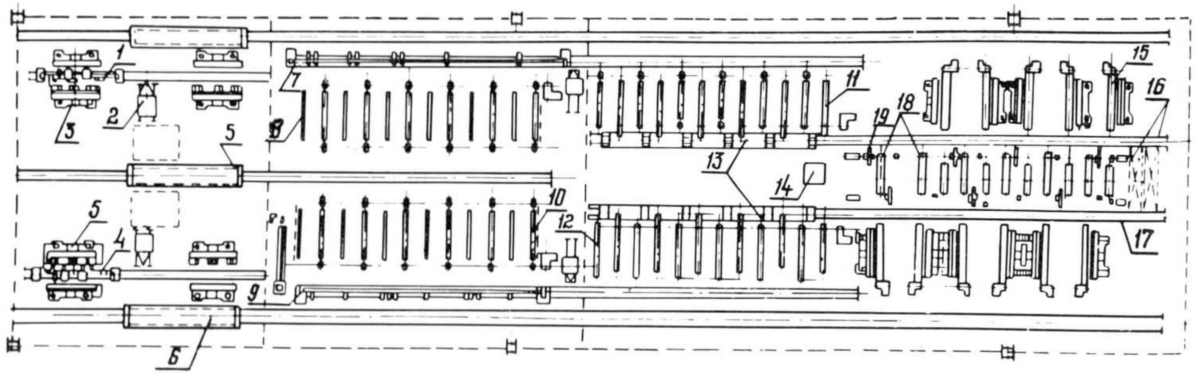

Fig. 6. Lay-out of flow line for assemblage and welding of roof-trusses made of angles: I - assemblage track for struts; 2 - welding machine; 3 - stock for struts; 4 - assemblage track for diagonals; 5 - stock for diagonals; 6 - electrified track; 7 - assemblage track for upper chord; 8 - stock of lower chord angles; 9 - assemblage track for lower chord; I0 - stock of lower chord angles; II - stock of upper chords; I2 - stock of lower chords; I3 - tilter of chord; I4 - control panel; I5 - in-feed roll-table; I6 - bridge crane with welding machines; I7 - stationary table; I8 - rotating table; I9 - positioning post.

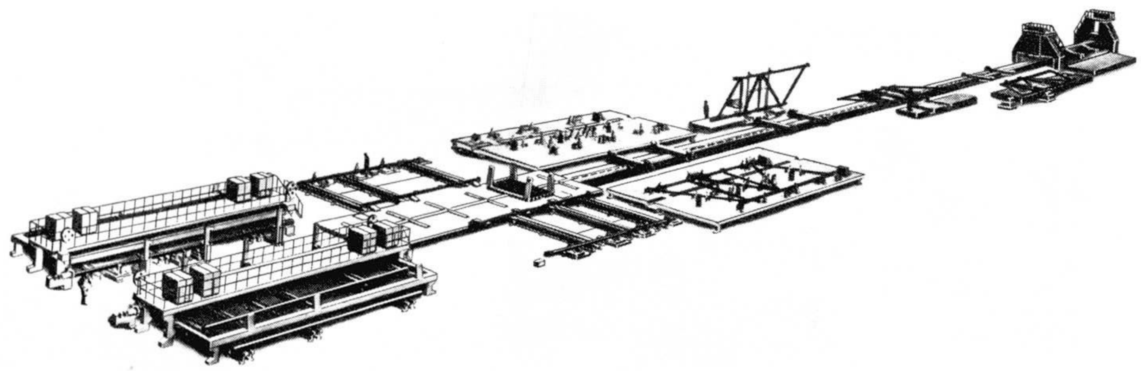

Fig. 7. General view of flow line for assemblage and welding of roof-trusses made of tubes.

stock feed racks 3 and 5 to assembly trucks 1 and 4 and are welded with resistance spot-welding machine 2. Finished diagonals and posts are loaded by an overhead bridge crane on to truck 6 and are moved to the zone of total assembly. Top and bottom chords of trusses are assembled in assembly trucks 7 and 9 and then are moved to the zone of total assembly. The feed of diagonals and posts to assembly jigs is carried out by infeed conveyors 15 and then they are positioned, locked and secured by the jig mechanisms.

Total assembly of roof trusses is carried out automatically by means of welding bridge cranes 16.

Technical-and-economic characteristics of the automated flow line for roof trusses made of angles with parallel chords are as follows:

Area, sq m.	2040
Output, thou. t/year.	25
Flow line cycle, min.	15.6
Number of workers serving the line at one shift work, men	11
Annual production per worker, t	1780
Annual output per 1 sq m of the production area, t.	12.3

The flow line for roof trusses with parallel chords fabrication of tubes (spans 18 and 24) is shown in Fig. 7.

The fabrication process involves the following operations: assembly and welding of bearing plates; assembly and automatic welding of flanges and spherical inserts to top and bottom chords; positioning and automated welding of the bearing plates to the upper chord; positioning and semi-automated welding of secondary members to the bottom chord; total assembly of the trusses; operational welding of the trusses (along the reverse side of the top and bottom chords); quality control of the finished trusses.

The flow line has the following zones (see Fig. 8): the zone of top chords assembly and welding; the zone of bottom chords assembly and welding; trusses total assembly zone and trusses welding zone.

In the zones of top and bottom chords assembly and welding the following operations are carried out: secondary members assembly and welding, their welding to the top and bottom chords, removal of the chords from the jigs and transfer to the assembly zone.

The zones of trusses assembly and welding are provided with two assembly jigs and three tilting tables for roof trusses welding.

Roof trusses assembly is carried out on two fixed benches 10. A special transport crane 11 performs all operations on components placing and removal of the assembled truss. Trucks are provided for feeding of components sets and subassemblies to the total assembly zone as well as for the transferring of the assembled trusses to the zone of welding: one truck is intended for placing and transporting of the assembled truss to the zone of welding and the other is intended for a set of blanks distribution and feeding to the zone of assembly. Trays with transverse members and a set of chords are placed onto the trucks.

Welding of trusses is carried out at the corresponding positions, at which there are placed lower tilting jigs, rotating the article 90° and 180°; the reference position is maintained by

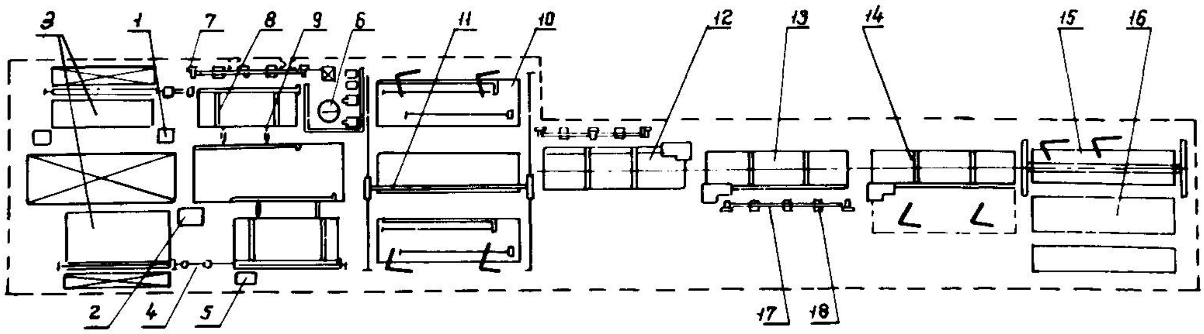

Fig. 8. Lay-out of flow line for assemblage and welding of trusses made of tubes; I-set-up for automatic welding of inserts and flanges; 2 - flange automatic welding machine; 3 - stock; 4 - overloading device of chords; 5 - set-up for automatic welding of plate assembly unit; 6 - bearing plates assemblage and welding section; 7 - bearing plates assemblage and welding bench; 8 - horizontal stock; 9 - overloading device; 10 - truss assemblage set-up; 11 - transshipment crane; 12 - left-side tilter; 13 - right-side tilter; 14 - 180°-tilter; 15 - full rotation tilter; 16 - control bench; 17 - semi-automatic equipment hook-up device; 18 - semi-automatic welding machine.

two-posts full-turn tilter 15, which may rotate the article 360°. Interoperational transporting is performed with the help of a transverse conveyor. A stationary checking table 16 is provided at the zone of quality control for a sampling inspection. Technical-and-economic characteristics of the mechanized flow line for trusses of tubes fabrication are as follows:

Flow line area, sq m.	1700
Output, thou. t/year.	20
The line cycle, min	10
Number of workers serving the line at one shift work, men	17
Annual production per worker, t	624
Annual output per 1 sq m of the production area, t.	11.7

The flow line for crane girders production consists of two zones: assembly and welding of main crane girders (Fig. 9) and assembly and welding of crane girders (Fig. 10).

At the line of main crane girders assembly and welding the main girders of eight gauges are fabricated, which are designed for end and intermediate crane girders 6 and 12 m long (welding of flanges to webs).

The entire procedure consists of the following operations: assembly of two flanges and a web, tacking of flanges to a web (item I); welding of flanges to the web with a field weld, rotating 180°, placing and welding of erection strips (item II); I - girders 1st and 2nd horizontal seams welding and rotation of the girders during welding (items III, IV); welding of seams 3 and 4 and rotating (items VI and VII); cutting off the strips and straightening of the girders (item VIII); ends milling (item IX).

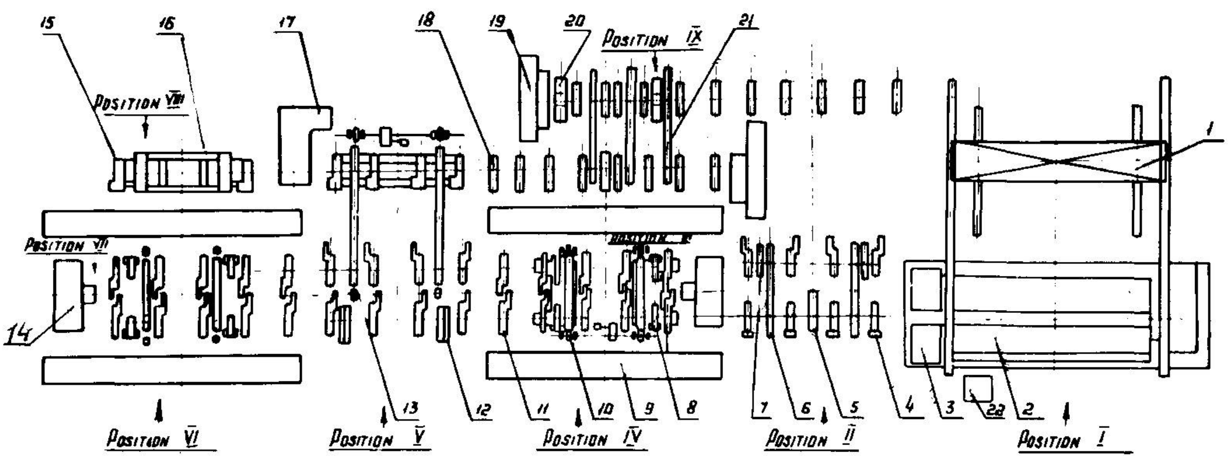

Fig. 9. Lay-out of flow line for maingirder fabrication: 1 - magnetic sheet steel stacker; 2 - in-feed; 3 - assemblage-and-welding stand; 4 - receiving roller; 5 - output set-up; 6 - conveyor; 7 - tilter; 8 - tilter; 9 - welding machine; 10 - conveyor; 11 - driving roller; 12 - tilter; 13 - conveyor; 14 - flux loading device; 15 - lifting roll-table; 16 - chain-tilter; 17 - straightener; 18 - driving roller; 19 - edge-milling machine; 20 - positioning mechanism; 21 - conveyor; 22 - welding-machine rectifier.

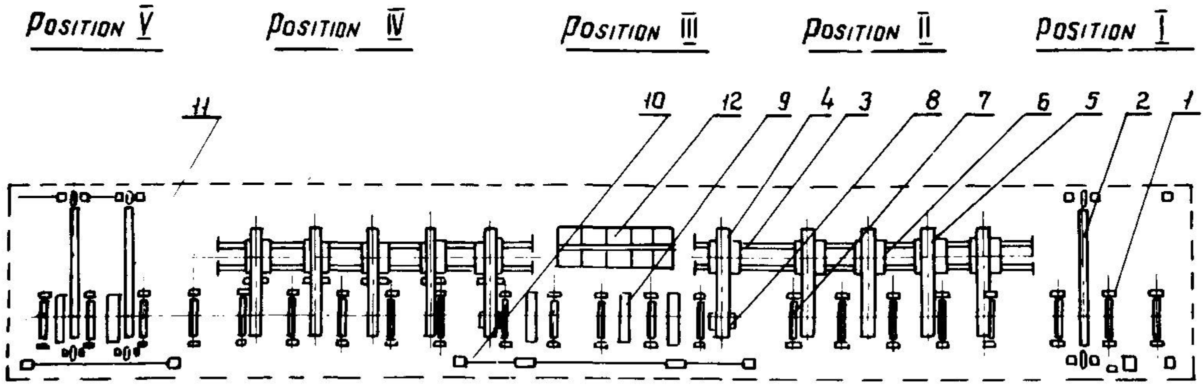

Fig. 10. Lay-out of flow line for completing processes of crane-girder fabrication: 1 - roll-table; 2 - conveyor; 3 - stock; 4 - edge-plate positioning and clamping device; 5 - stiffening-ribs in-feed and welding set-up; 6 - stiffener infeed device; 7 - roll-table; 8 - pneumatic lifter with clamp; 9 - tilter; 10 - metal member for semi-automatic equipment over hang; 11 - tilter; 12 - welding machine rectifier.

The flow line consists of three zones: 1) a shaft assembly and welding; 2) flanges straightening; 3) ends milling.

The components (flanges and webs) are delivered by plate-stacker 1 from the storage area to assembly-and-welding stand 3, equipped with two welding heads, which weld an I-girder flange and web tightly compressed by means of horizontal and vertical rollers. Then the girders are moved to a roller conveyor 4 and then by means of a transporter 6 to a tilting device 7, which rotates the girder 180° and as a result the field welds are turned their back sides which helps to form a strong weld. A girder is welded on two welding stations successively (items III and IV), after which it is turned 180° with tilter 12 and is moved to positions 6 and 7 for making the third and fourth web welds. Then the girder is moved with the conveyor 13 to the straightening machine 17 after which it is moved again with tilter 16 for straightening the second flange. By means of a roll-table the girder is passed to the face-milling machine 19 in the milling section. The finished I-beams are moved from the line by means of a roll-table to the stock of the general assemblage and welding line.

Technical-and-economic data for a mechanized line fabricating crane girder webs are as follows:

Area, sq m.	2210
Productivity, thou. tons per year	20
Cycle, min.	14
Number of workers serving one line per shift, men	8
Annual output per one worker, tons.	1167
Annual output per one sq m of area, t . . .	8.45
Labour consumption, men-hours/ton	1.49

The crane girder assembly and welding line includes the following operations: positioning of stiffening ribs and welding them to the web on one side of the girder; positioning of end plates, all-round welding of the plates to the girder, completing of unwelded connections in stiffening ribs; positioning and welding of the stiffening ribs on the other side of the girder; completing of unwelded zones in the stiffening ribs and finishing the welds.

The line performs the complete cycle of operations for assemblage and welding of crane girders. Hole drilling in webs is done in the specialized section outside the line; the line can be equipped with various machinery for different operations; the line is used for assemblage and welding of girders of the entire range of sizes; all the handling and inter-operation transporting of the members is done with separate means incorporated in the equipment of the line.

Bridge cranes or similar material handling equipment are used for moving the members to the line and transportation of finished products from the line.

The crane girder assemblage and welding line includes the following sections: 1) stocking of webs and moving them to final assemblage and welding (position 1); 2) positioning and welding of stiffening ribs to the web on one side of the girder and end plates (position 2); 3) completing stiffening rib welds and all-round welding of end plates (position 3); 4) positioning of stiffening ribs and welding them to the web on the other side of the girder (position 4); 5) completing the stiffening rib welds and cleaning of the welds (position5).

I-beams are moved to roll-table 1 by means of conveyor 2 whence they are passed to roll-table 7 and are put in the working position. In position 2 welding connections of stiffening and bearing ribs on one side of the girder are done, the girders coming from stock 3. The in-position welding of bearing and stiffening ribs is done with the automatic welder by means of devices 5 and 6.

The over-all sizes of automatic welders allow to place only two machines, therefore the first stiffening rib is welded to the web on one side only, the remaining ribs being welded on two sides. Further welding and positioning of ribs is done with an interval of 1.5 m. The girder with stiffening ribs welded to one side is lowered on to roll-table 7 with device 8 and is moved along the table to position 3 where stiffening rib welds are completed and bearing ribs are fully welded. After that the girder is turned 180° with tilter 9 and is passed along roll-table 7 to position 4 where a similar operation is carried out on the other side of the girder. Then in position 5 the welds are finished and cleaned.

Technical and economic data for the crane girder fabrication flow line are as follows:

Area, sq m.	780
Productivity, thou.tons per year.	20
Cycle of line, min.	14
Number of men engaged on the line per one shift, men	5
Annual output per one skilled worker, t	1693
Annual output per one sq m of area, t	28.7
Labour consumption,men-hours/t.	1.44

Overall technical-and-economic data for the two crane girder fabrication lines are as follows:

Productivity: thou. pieces per year	13.7
thou. tons per year	20
Cycle of line (average), min.	14
Area, sq m.	2990
Number of workers per one shift, men.	13
Labour consumption for production of one conditional average piece, men/hours	3.3
Annual output per one skilled worker, tons.	770

The automated flow line (Fig. 11) for assemblage and welding of lattice purlins consists of three main sections: 1) assemblage and welding of the upper chord; 2) assemblage and welding of the lattice purlin; 3) testing and control.

In the upper chord assemblage and welding section the sequence of operations is as follows: stock feed racks 1 move to assemblage roll-table 2 upper chord channels (pre-orienting them in the design position) until they reach the zone of the pressure contact welder 3. Automatic device 4 positions the membrane between the two channels and contact welder 3 welds them. The stepped feeding system repeats the production process after which the welded chord is moved to roll-table 6. The mechanisms of stock 7 remove the chord from the roll-table.

In the assemblage and welding section purlins are welded in two positions. In the first position the diagonals and the lower cover plate are placed into the jig, in the second one, the remaining purlin members are placed in the jig.

Automatic device 16 places the purlin lower cover plate into jig 9. The right and left diagonals are passed from stock feed racks 12 to conveying device 17 and placed in the jig. The jig mechanisms position and fasten the members. Then the jig is moved into the second position.

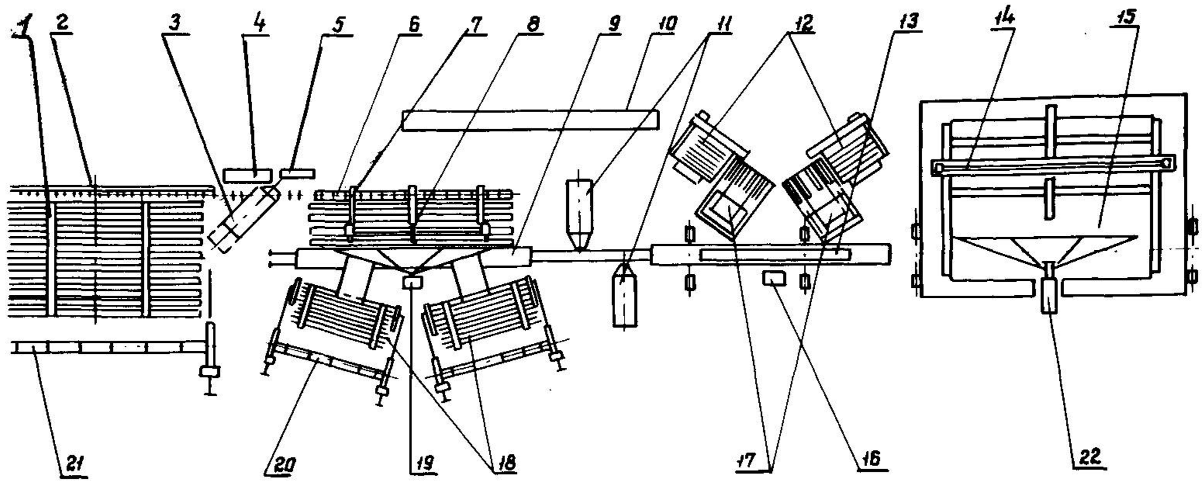

Fig. 11. Lay-out of flow line for assemblage-and-welding of latticed purlins: 1 - upper chord stock; 2 - assemblage roll-table; 3 - contact pressure welding machine; 4 - membrane automatic operator; 5 - stepped in-feed mechanism; 6 - in-feed roll-table; 7 - finished upper chord stock; 8 - chord stacker; 9 - track jig; 10 - control panel; 11 - contact pressure welder; 12 - stack; 13 - overloading; 14 - test bench; 15 - finished purlins accumulator; 16 - lower cover-plate automatic operator; 17 - transport facility with diagonal stacker; 18 - lower chord stock; 19 - upper cover-plate automatic operator; 20 - lower chord magnetic stacker; 21 - upper chord channels magnetic stacker; 22 - tilter.

Each of the stock racks 18 feeds one lower chord member having pre-oriented them in the design position and place the lower chord members into jig 9 where they are fixed and fastened. Placer 8 takes the upper chord from the stock and passes it to the lower chord members and the diagonals which are on the jig. The upper chord is fixed with jig mechanisms. The purlin assembled in the jig is moved to the pressure contact machines (11) zone where the purlin is welded. One machine welds the points along the upper chord, the other, points along the cover plate.

After welding, the jig is returned to the initial position and loader 13 takes the finished item off it. The cleared space is taken by the members of the next purlin and the process is repeated.

Loader 13 moves the latticed purlin to the welding completion section where testing and control are performed and moves it in the horizontal position. The tilter turns the lattice purlin 90°. Before welding the bearing ribs purlins are stored in stock 15. The purlin is passed by the stock to the welding section and is placed on the bearing ribs prepared for the operation. After welding the ribs to the purlin it is moved by the conveyor to testing table 14.

Assemblage and welding of a purlin are carried out by three operators per shift. The line is controlled from panel 10 according to a pre-set programme.

Technical and economic data for the automated latticed purlin fabrication line are as follows:

Area, sq m.	1270
Productivity, thou. tons/year	6
Cycle of line, min.	12.5
Number of people servicing the flow line per shift, men.	5
Annual output per 1 worker, t	628
Annual output per 1 sq m, t	5.4
Labour consumption, men-hours/t	2.48

A view of the latticed purlin assemblage flow-line is shown in Fig. 12.

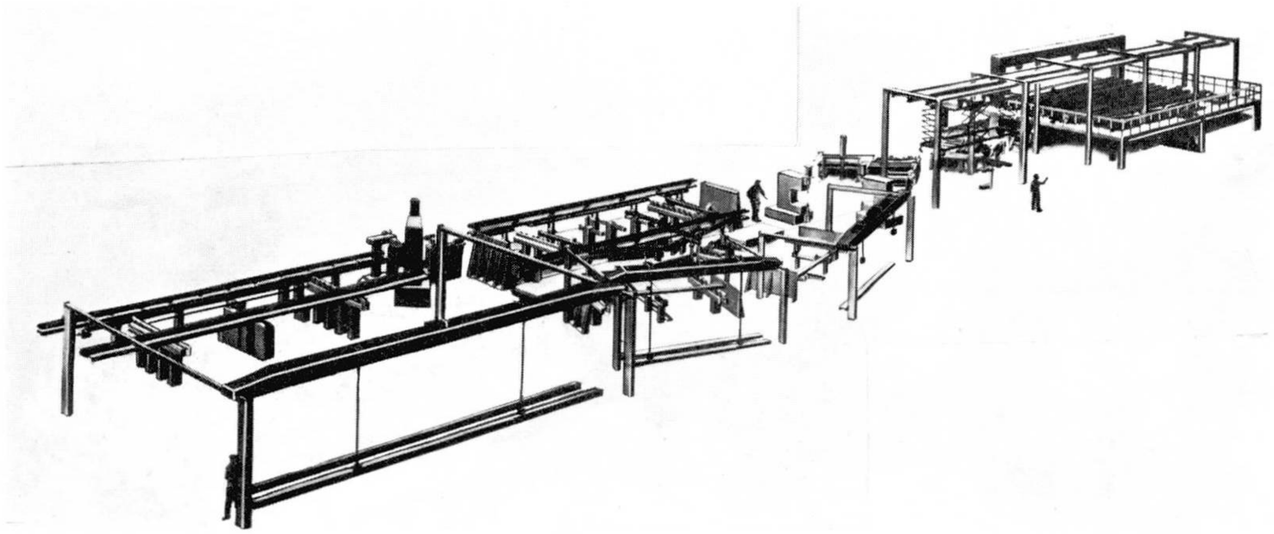

Fig. 12. General view of latticed purlin assemblage-and-welding flow line.

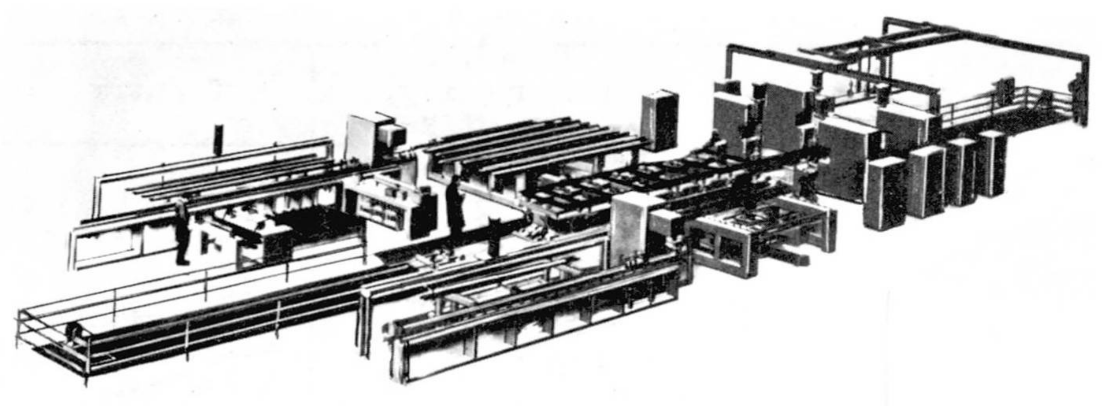

Fig. 13. General view of monitor sashes assemblage-and-welding line.

Figures 13, 14 and 15 show flow lines for fabricating members of monitors for buildings.

In table 2 the design capacities of flow lines for processing, assembly and welding accepted in the USA, France, Federal Republic of Germany, German Democratic Republic, Great Britain and other countries are given.

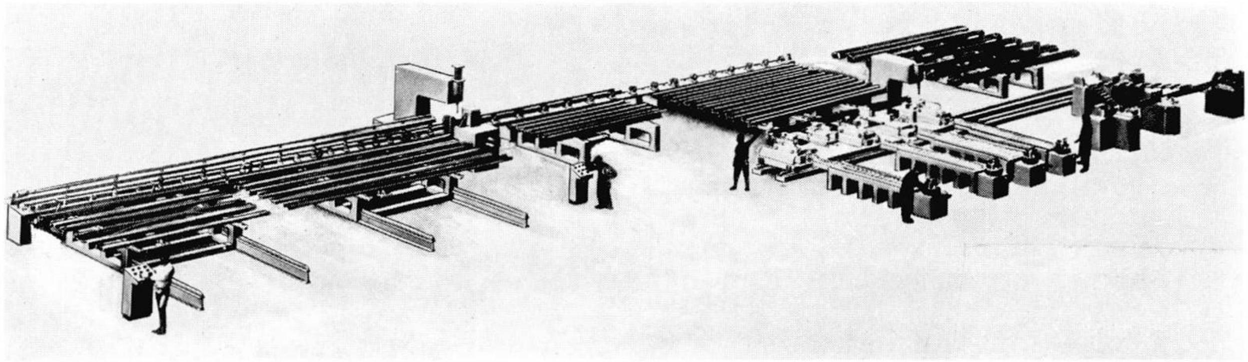

Fig. 14. General view of monitor trusses flow line.

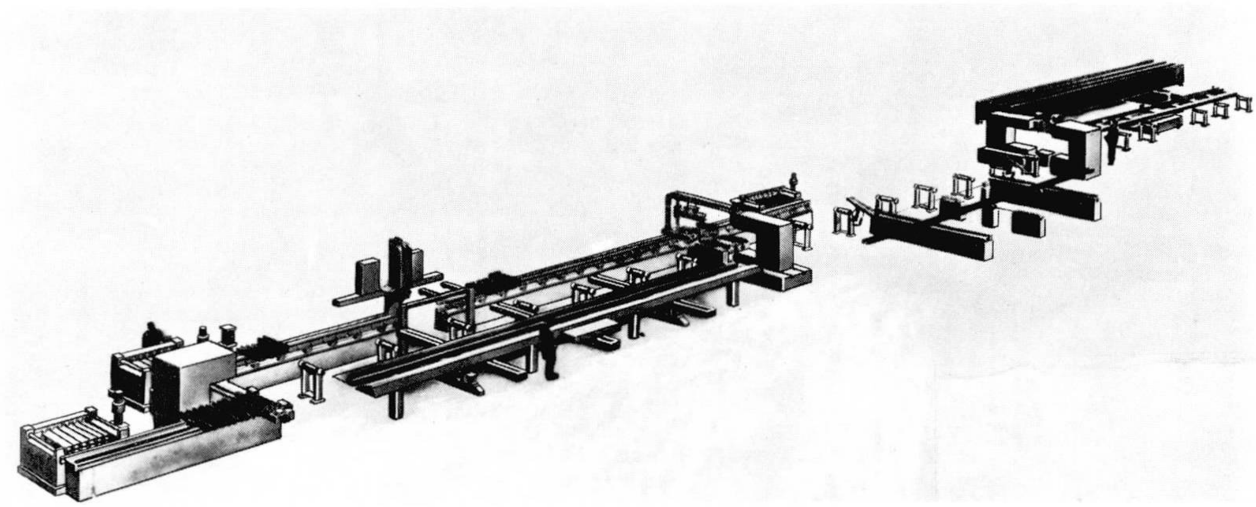

Fig. 15. General view of monitor edge girder assemblage-and-welding flow line.

Table 2

Flow line designation	Design capacity, thou. t/year	Country
For processing of:		
plates for bunkers	20	USA
floor beams	2	USA
I-beams, channels and angles	10 15	Great Britain Federal Republic of Germany
medium-size angles	10	France
plates	18	Japan
For assembly and welding:		
open truss joists	20	USA
space structures made of tubes	12	German Democratic Republic
welded I-girders	20	Sweden Federal Republic of Germany

In the USA at the manufacturing division of "Republic Steel Co." the process of open truss steel joists fabrication has been automated. The joist chords made of ⊓-shapes are fabricated on a flow line equipped with program controlled shaping mills and the trusses of the joists are fabricated at a separate flow line. The output of such a flow line is 20 000 t annually. A flow line for the joist truss fabrication is shown in Fig. 16, a flow line for the joist upper chord fabrication is shown in Fig. 17. Fig. 18 shows the loading of the Republic joists.

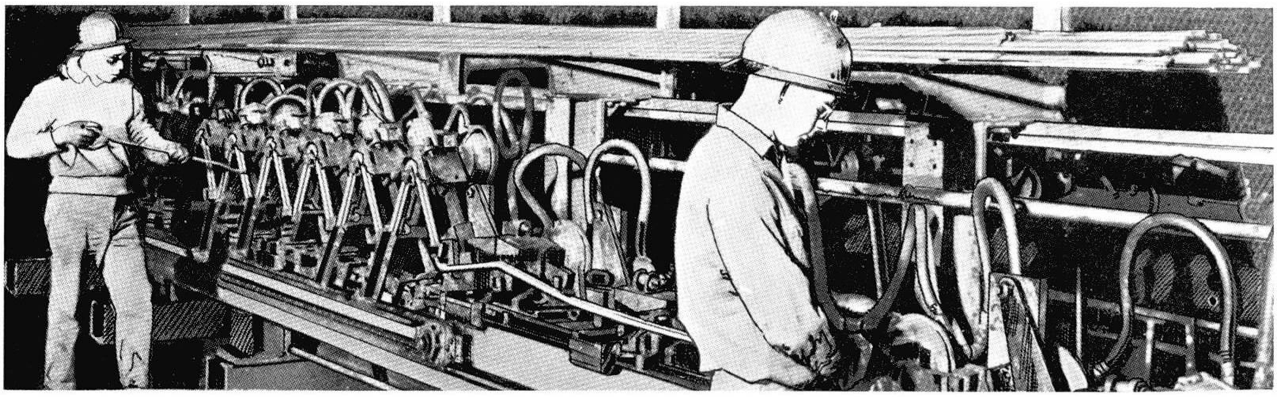

Fig. 16. General view of latticed purlin fabricating line ("Republic Steel").

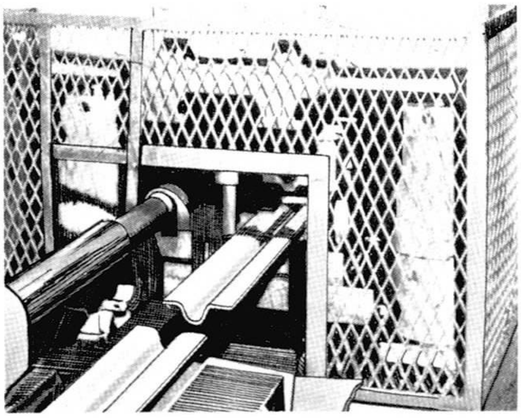

Fig. 17. General view of flow line for the fabrication of purlin upper chord ("Republic Steel").

The "Butler Manufacturing Company" in the United States fabricates bunkers for grain storage. The production of bunkers by the "Butler Manufacturing Co." is performed on flow lines. The technological process of corrugated sheets for a cylindrical body, roofs, posts, floor girders and stairs is organized at the up-to-date level of automatization. The flow line 100 m long (see Fig. 19) occupies the area 1200 sq m. The output of the line is 20 thou.t.

Fig. 20 is a lay-out of a flow line of sheets for a bunker roof fabrication.

In GDR the plants for space structures and frames fabrication have been generaly accepted (Fig. 21).

In Great Britain the firm "Boulton and Paul" has put into operation the flow line for beams produced with the output of 10 thou.t per year (Fig. 22).

The sheet structures plant at which two flow lines for steel

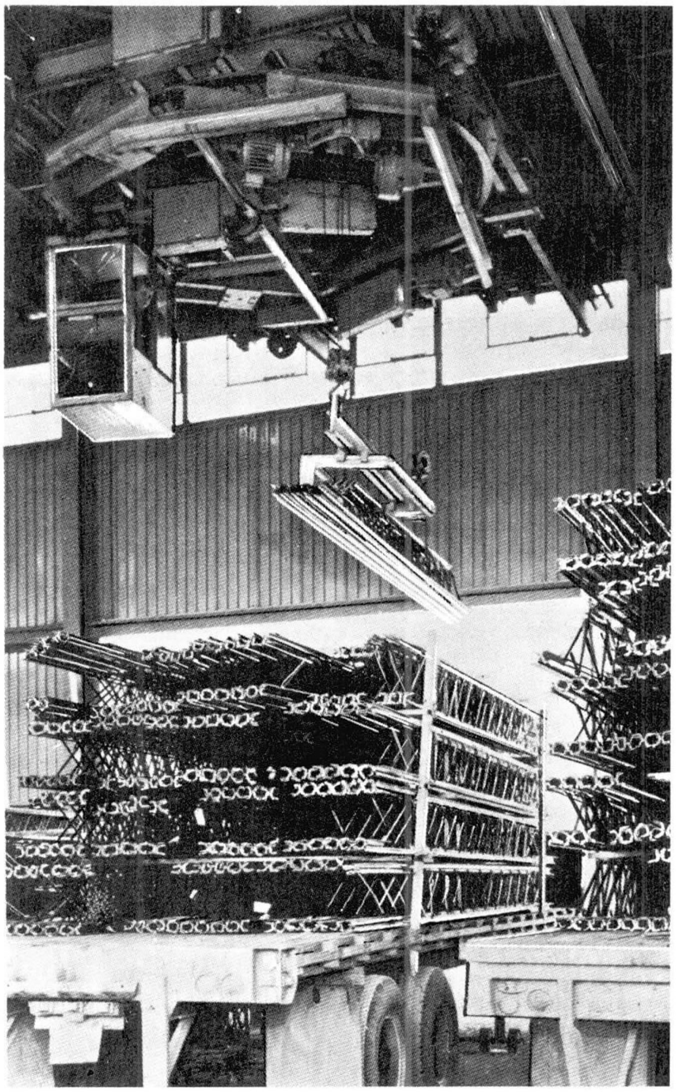

Fig. 18. Latticed purlins loading ("Republic Steel").

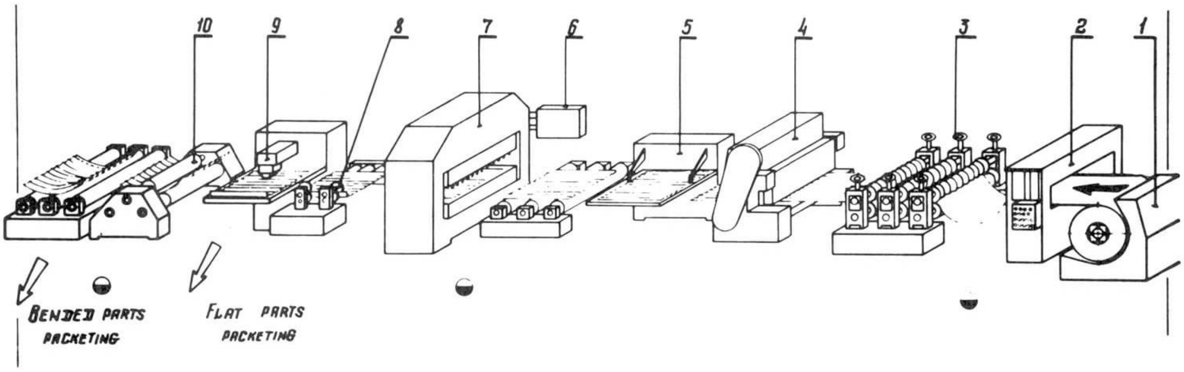

Fig. 19. Lay-out of flow line for fabrication of corrugated sheet for cylindrical body of grain-storage bunkers. ("Butler Manufacturing Company"). 1 - coil support; 2 - uncoiling device; 3 - corrugating device; 4 - shears; 5 - length-size control set-up; 6 - tableau; 7 - hole-punching presses; 8 - edge-straightening machine; 9 - counter; 10 - rollers.

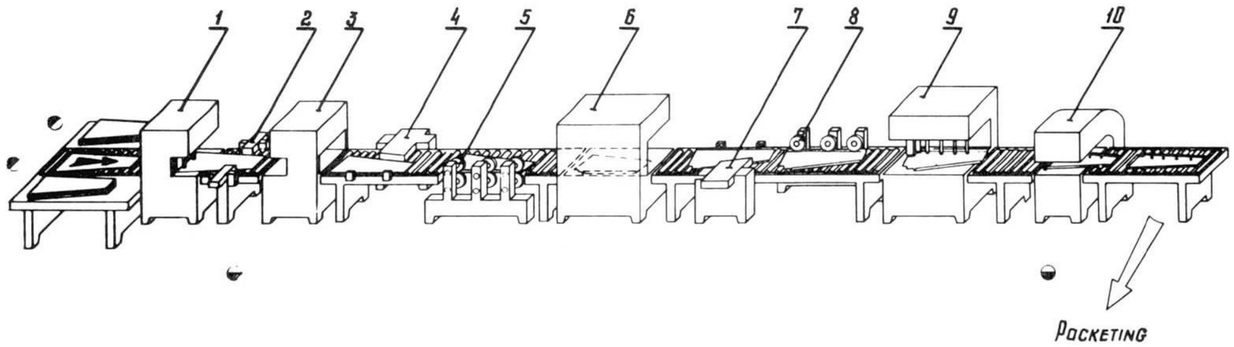

Fig. 20. Lay-out of flow line for roof sheets fabrication. 1 - edge cutting and hole-punching press; 2 - member positioning device; 3 - cutting press; 4 - right-side corrugation machine; 5 - member positioning device; 6 - angle-cutting and hole-punching press; 7 - member repositioning and orientation device; 8 - left-side corrugation device; 9 - angle-cutting and hole-punching press; 10 - eaves bending press.

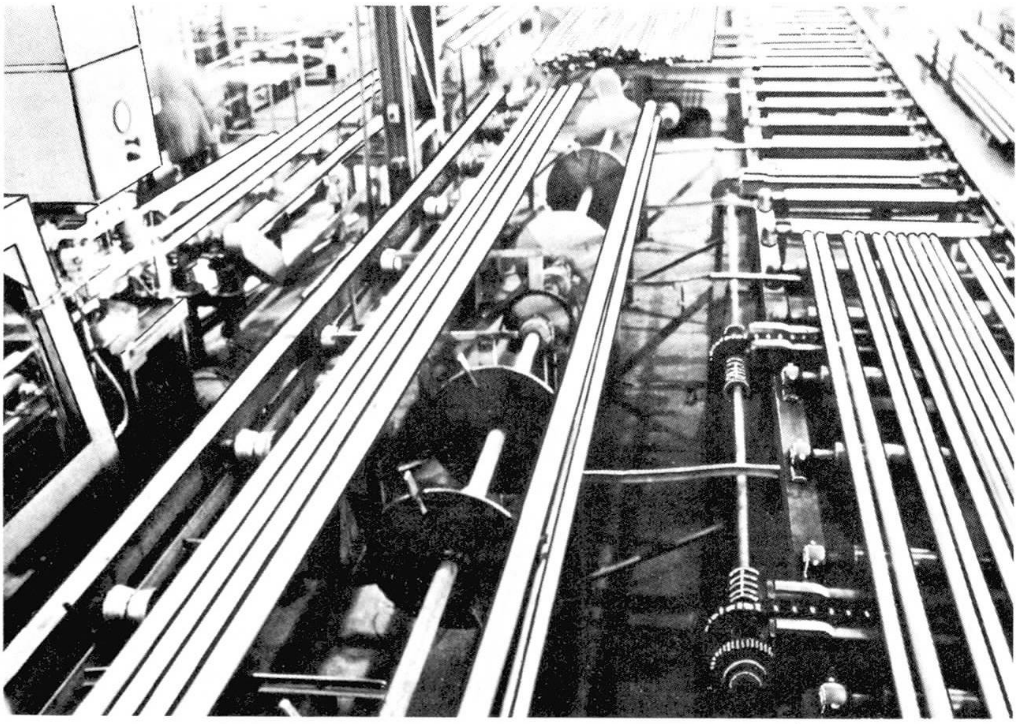

Fig. 21. Flow line for fabrication of structural members of tubing.

sheets processing, cleaning and painting are used is located near Tokyo, Japan. The output of each line is 18 thou.t annually.

The work on developing of such plants with in-line production is being carried out in the United States, Great Britain, Japan, GDR and other countries.

In the USSR the primary task at the developing of such plants was to find out the field of in-line production application.

At the first stage it was suggested to use in-line production

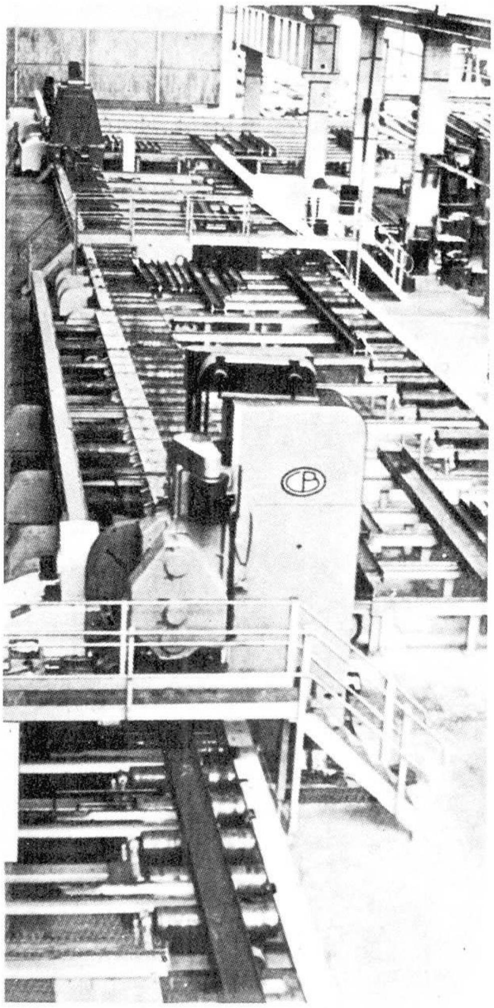

Fig. 22. Flow line for processing girders in the "Boulton and Paul Co.".

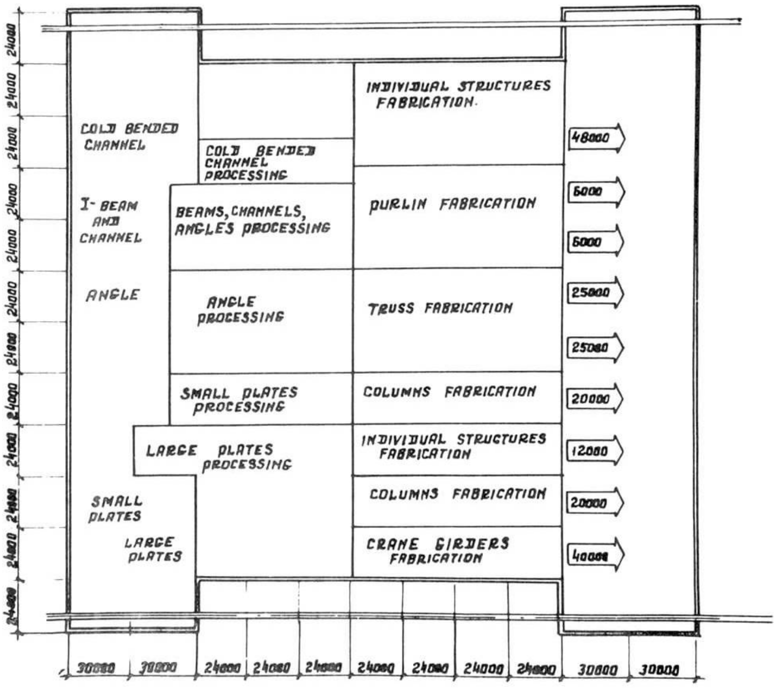

Fig. 23. General layout of the technological process in flow line production plants.

in the field of industrial buildings assembled from standardized components.

Investigations showed that production capacities of metal structures for industrial buildings on the basis of in-line production would reach approximately 900 000 t in 1980.

The volumes of in-line production and the corresponding number of flow lines are given in table 3.

At the construction of new plants it is important to determine the plant optimum capacity. It is generally accepted, that the optimum capacity is determined on the basis of the most complete usage of high-duty equipment and automated lines provided that, the occupation factor for the equipment used is 0.8.

Research works carried out in this field showed that plants optimum capacity depended also on the types of structural forms. The optimum capacity of a general purpose plant is up to 200 thou.t annually. The list of products of such a plant is given in table 4.

Optimum capacity of light structures of in-sets-delivery

Table 3

Main characteristics denomination	1980
Total volume of metal structures fabrication, in thou.t	3.6
Volume of in-line production, in thou.t	6-9
Flow lines number:	
for processing	38-50
for assembly and welding	30-45
for painting	30-35

Table 4

Structures name	Annual output	
	thou.t	%
Columns	40	20
Roof trusses	50	25
Lattice girders	12	6
Crane girders	40	20
Braces	18	8
Framework members	20	10
Braking members	8	4
Miscellaneous structures	12	6
Total	200	100

plants depending on the list of products is within the limits of 50-100 thou.t.

Interesting investigations on determination of light structures plants optimum capacity have been carried out by "Butler Manufacturing Company", USA. In table 5 are given characteristics of three plants: the first is a non-automated plant with capacity 1 mln sq m of structures area (30 thou. t per year), the second is a partially automated plant of the same capacity and the third is an automated plant with a capacity of 2 mln sq m (60 thou.t per year).

The table shows the advantage of the automated plant with annual capacity 2 mln sq m of buildings (60 thou.t) with in-line production.

In the USSR the work on determination of the plant optimum capacity depending on the type of the specialized structures there fabricated is being carried out.

At the present symposium we bring for discussion the project of a general purpose plant for in-line production of industrial building structures with a capacity 20 thou.t. The main facilities of the plant are concentrated in the main building with the area 77 760 sq m (not including a painting shop). The plant is equipped with seven highly mechanized flow lines for beams, channels

Table 5

Main characteristics denomination	non-automated plant sq m (30 thou.t)	semi-automated plant sq m (30 thou.t)	automated plant sq m (60 thou.t)
Annual production - sq m of building area	1 000 000	1 000 000	2 000 000
Cost of machines and equipment (without the building and the land cost), in dollars	2 860 000	3 780 000	5 500 000
Number of workers (a sum of two 8-hour shifts)	200	175	280
Annual production (sq m) per capital investment, m^2/dollars	0.35	0.265	0.365
Annual production per worker, sq m	5 000	5 700	7 150

and angles processing and with two flow lines for plate members processing. In an assembly-and-welding shop there are two flow lines for lattice girders fabrication, 2 flow lines for roof trusses assembly and welding, 2 flow lines for two-branch lattice columns assembly and welding and, at last, 2 flow lines for crane girders assembly and welding. The total lay-out of this plant technological process is shown in Fig. 23.

All flow lines include some machines, provided with manipulators and other devices making their operation automatic according to the programs, which perform all auxiliary operations.

The fabrication process is controlled by means of an automated system which covers all sides of the production process.

Comparison of the data for the plant with the in-line production of steel structures with the data for a conventional plant is given in table 6.

The comparison of the above-mentioned data shows that the in-line production of steel structures which uses highly mechanized flow lines gives definite advantages. The output of finished products per 1 sq m of the production area is 1.5-2 times higher, the labour productivity is 2-3 times higher, the cost price of the finished product is 20-30% lower.

At the end of my presentation I'd like to formulate the main aspects of the theory of structures fabrication technology on the basis of in-line production, including:

- research and development of constructive forms, which ensure progressive methods of automated in-line production;
- determination of the field of application and the volumes of in-line production;
- investigations in the field of unification and standardization of structural members with the aim of increasing of production in series, quality and reduction of structural mass and labour;
- research and development of new technological processes and new equipment for mechanized and automated fabrication processes;
- development of main principles of lay-out of flow lines

Table 6

Characteristics	Plant with in-line production of structures (project)	Plants in operation
Output per 1 sq m of production area, t/sq m	2.66	1.77 - 1.87
Average annual production per one worker, t	157	63.1 - 87.9
Cost price of product fabrication (without metal cost), rubs.	45.6	55 - 60

for metal preparation, processing, assembly, welding and painting for a wide range of beams, latticed and thin-walled structures;

- investigation of selection methods for optimum arrangement of specific technological processes for different structural forms;
- introduction of new flow lines for mechanized and automated fabricating process, among them surface preparation lines, sectional steel and plates processing lines, structures assembly and welding lines and lines of structures painting;
- developing of a new type of a plant for metal structures fabrication on the basis of quite new technological solutions with large-scale mechanization and automatization of in-line production and with automated control system;
- development of measures for steel structures plants reconstruction in specialized plants;
- development of measures for improvement of organization and fabrication process planning;
- development of mathematic methods of optimization of manufacturing process.

Problems of technological progress in the field of metal structures production intensification require a rapid transition to a more up-to-date type of production - production in series, specialized production based on mechanized and automatizated in-line fabrication of all operations. Only large-scale mechanization and automatization of in-line production would make it possible to speed up technical progress in steel structures production, to increase productivity and product quality.

To our opinion scientists and engineers of all countries face the problem of great economic importance - to re-organize the process of steel structures fabrication to in-line mechanized and automated process of mass production. It may be stated, that mechanization and automatization of the production process are the main aspects of the scientific-and-technical revolution in the field of metal structures development.

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