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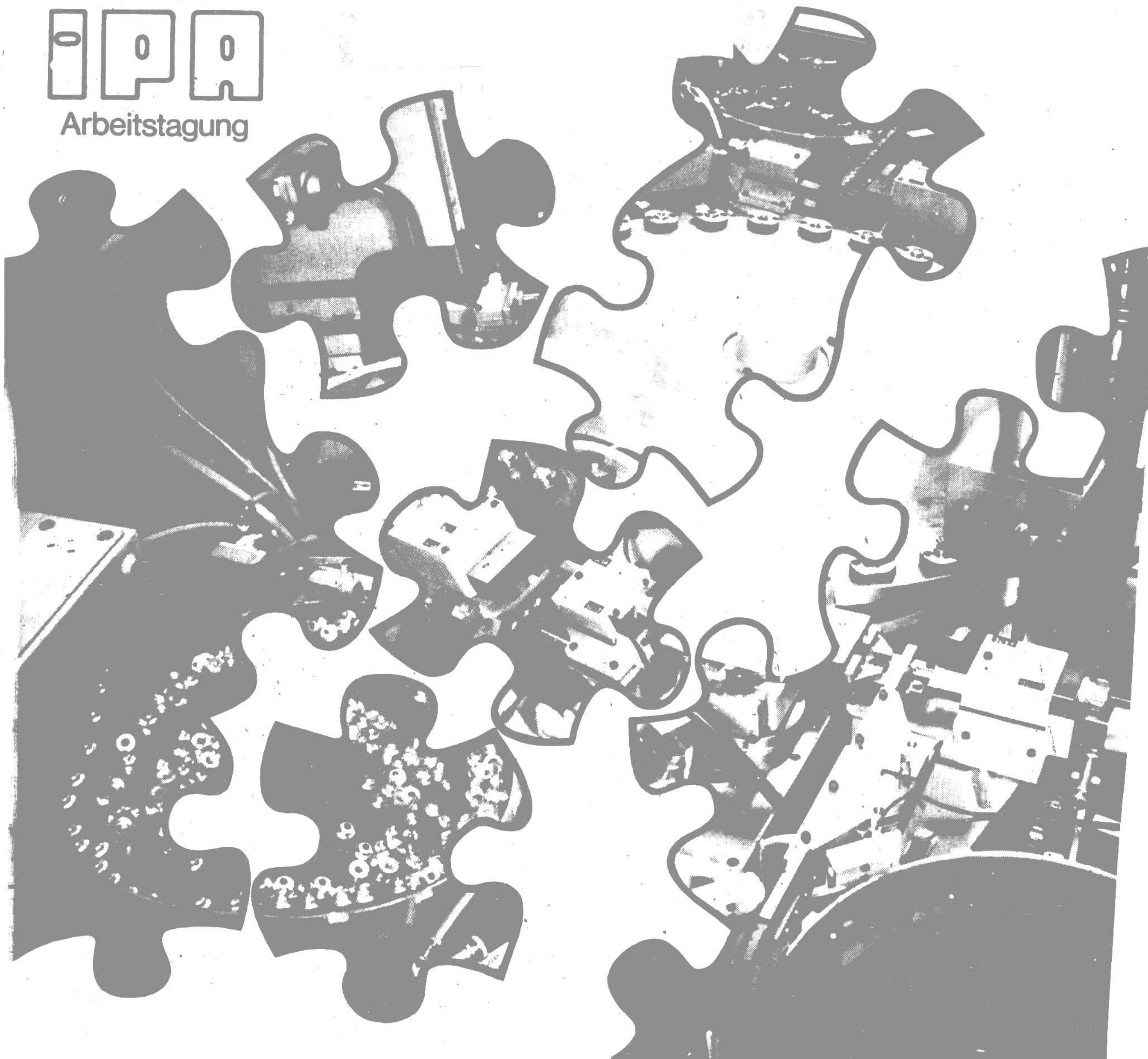

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AUTOMATIC ASSEMBLY - STATE-OF-THE-ART

H.-J. Warnecke, J. Walther
Fraunhofer-Institut für Produktionstechnik und Automatisierung (IPA) Stuttgart, West Germany

SUMMARY

Many radical changes have been happening in the field of automated assembly. Demands for a higher degree of flexibility are being placed on conventionally automated installations. On the other hand it is necessary to further automate manual and partly automated assembly systems. For these reasons new, flexible systems are appearing in the fields of both manual as well as standard automated assembly.

The range of conventional and new automatic assembly installations, from single machine to transfer line, is presented. With reference to examples hitherto realized, the properties, ranges of application and present stage of development are described. Furthermore, the existing obstacles to automation are pointed out and the question of further developments is considered.

1. Ranges of Application of Automated Assembly Systems

Successfully realized partly- and fully- automated assembly systems exist for components with a total mass of less than one gram , which are assembled with cycle times of fractions of a second, up to units with a total mass of over 100 kg, whose work contents may be over one minute per station. Figure 1.1 shows an overview of the main areas of application of automatic assembly systems. The boundaries shown are, however, not to be regarded as stationary. The individual systems are considered in more detail below. Their typical properties are pointed out and application examples are explained.

2. Cam-driven Assembly Automats

As can be seen from Figure 1.1, these machines are used if very short cycle times, within the range of 0.2 to 5 seconds, must be realized. Assembly automats today exhibit a high technical state of development. They are constructed as either longitudinal transfer- or as rotary-table systems.

The cam-driven assembly automats are driven and controlled mechanically. The cycle sequence and movements are fixed. The assembly process is divided into many single processes; each individual process being carried out at a special station. These conventional assembly systems are manufactured mainly by small and medium-size firms, which supply the machines according to customer requirements. Many manufacturers have confined their production to a small product spectrum, and can therefore offer problem solutions specifically directed towards special assembly technologies and product-specific requirements. Some firms build assembly machines according to a modular system, which enables very economic solutions. Furthermore, the use of standardized elements and interfacing points enables easy re-setting, and therefore increased flexibility.

A typical example of a cam-driven assembly automat is shown in Figure 2.1. It represents a longitudinal transfer automat which assembles typewriter colour ribbon cassettes in a cycle time of 2 seconds.

The assembly sequence is as follows:

- feeding and insertion of case
- feeding, alignment and insertion of takeup core
- feeding and insertion of colour ribbon
- setting of colour ribbon to locate start of it
- unwinding starting end of ribbon and connecting it to takeup core by means of plastic wire clip
- setting colour ribbon and takeup core into housing
- tightening of ribbon
- feeding and attachment of lid
- lifting out completely assembled parts, and securing lid by ultrasonic welding
- lifting out incompletely assembled parts.

3. Pneumatically-driven Assembly Automats

The basic design of these assembly automats corresponds to that of the cam-controlled machines already described. Contrary to these, however, the operation of the interlinking device and of the individual work elements takes place individually and via compressed air.
The control and supervision of the assembly process are, in modern systems, taken over by programmable memory controllers.

The main range of application of the pneumatically-driven assembly automats is for parts which must be assembled with cycle times of 3 to 10 seconds, and which exhibit several variants. The effort required for re-setting and adapting with the introduction of additional product variants is lower than that for the cam-driven machines, but still high enough to necessitate the assembly of the parts by medium or large batch sizes.

Figure 3.1 shows an assembly installation for various types of bullets. The installation consists of 3 pneumatically-driven rotary indexing automats for the mixing and dosing of the powder, the pre-assembly of one bullet half, and the completion of the parts.

All movements of the assembly installation are electronically monitored and likewise each loading device is checked for the presence of the parts.

4. Flexible Building-block Systems

With the help of building-block systems, made up of standardised modules and basic units, both mechanized single work-places and flexible assembly automats, as well as complete assembly systems with line- or closed (e.g. square) structure may be constructed. Depending on the degree of automation, number of assembly positions and parts, diversity of types, batch sizes, as well as cycle time and work content per assembly station, it is possible, by the combination of the building block elements, to automate a large spectrum of assembly tasks.

The large range of application of these systems covers assembly cycle times of approx. 10 to 60 seconds, and workpiece weights from a few grammes to 10 kg.

The standard elements and modules available in the various unit assembly systems are groups of base units, conveyor belts, indexing rotary tables, workpiece carriers, magazines, feeding systems, movement modules (pneumatic and electrical NC-, Linear-, and rotational-units) and grippers as well as control and monitoring modules.

With the aid of these modules flexible assembly stations and -systems can be realized, so that variants of one workpiece can be assembled in mixed-model operation or in very small batches.

Nowadays the controllers are nearly exclusively built up as memory-programmable controllers. Although they are often associated with a higher price, they do offer advantages such as decreased planning effort, good adaptability, simple alteration and extension possibilities, fault diagnosis which can be integrated, and a high degree of re-usability in new assembly installations.

Typical workpieces that are assembled with the aid of flexible building block systems, are parts such as relays with many variants, small electric motors, valves, etc.
Apart from fully automatic assembly installations, partly automated systems can also be built up without any problems from the elements of the unit assembly systems.

Because of the standardized interfacing points between the transport modules and the base unit groups manual workplaces can very easily be integrated into an assembly system.

Figure 4.1 shows several components of a unit assembly system for partly- and fully- automated assembly installations.

5. Partly-Automated Assembly Transfer Lines

Assembly transfer lines are used as a rule in cases where workpieces with a total mass of more than 10 kg have to be assembled. The installations correspond to the layout of transfer lines used in metal-cutting production. The main users of these systems are the automotive and electrical industries. With degrees of automation of from 20 to 70%, and cycle times varying from 20 to 60 seconds, components such as motors, gear boxes, rear axles, front axle halves, shock absorbers, etc. have hitherto been assembled in assembly transfer lines. The structure of the assembly systems is usually pre-determined by the space available. The inter-linking of the manual and automatic stations for new installations in german firms takes place exclusively via friction roller conveyors.

The following operations have so far been automated with the use of assembly transfer lines:

- Joining operations such as tightening screws to a certain torque, pressing in pins, inserting crank shafts,
- Feeding operations such as the filling-in of lubricants and coolants, spray-covering of sealing material, application of adhesives,
- Inspection operations with respect to bearing clearance, sealing quality, etc.,
- Measurement tasks such as the measurement of the frictional moment, selective assembly,
- Marking such as colour marking, embossing, etching,
- Forming operations such as flangeing, bending, caulking,
- Handling functions such as insertion and ejection, rotating, turning over,
- Spot- and seam welding in chassis construction (which will not be dealt with within the scope of this report).

Joining operations which can so far not be automated are those with complex joining motions and with parts which cannot be ordered economically. Furthermore all kinds of repair- and adaptation work are still performed manually.

The assembly line for car differentials represented in the Figures 5.1 and 5.2 is a typical representative of the partly automated assembly transfer lines. It has been designed for a cycle time of 26 seconds. The space requirement is approx. 170 m^2.

Fourty five assembly pallets are automatically guided to the individual assembly and auxiliary stations on a circulating conveyor track, consisting of two longitudinal and two transverse conveyors designed as friction roller conveyor.

6. Programmable Assembly Systems

Assembly systems with industrial robots are hitherto only used in the assembly of small parts, whereby the cycle times are situated in the range from 15 seconds to several minutes. The programmable assembly systems may operate in the model-mix mode with one product having several variants, or they are used for small batch sizes and for batches containing different products. However, industrial robots require the same fixtures, feeders and other equipment for positioning the parts as is necessary for a conventional assembly machine. However, because of their free programmability and the possibility of programming monitoring strategies, simpler workpiece feeders and fixtures may be used. Furthermore tactile or optical sensors may be used. And last but not least many different assembly tasks on different products may be performed with the aid of a single assembly robot, and with only one set of fixtures and tools. In this manner the economic use of programmable assembly systems for the automatic assembly of small parts can be foreseen.

Because of the high adaptability of an industrial robot, the necessity of writing off the robot as a special machine within the production period of a single assembly product does not exist. The most widely used robot system for industrial assembly, and the first appearing on the market, is the Olivetti SIGMA-robot. A new version of this assembly robot was introduced in 1980. This assembly robot, now named Serie 3, incorporates a working volume increased by 160%. The previous stepping motor drives were replaced by d.c. motors. Thereby especially the acceleration behaviour was improved, which is of special significance in decreasing the cycle times for the commonly quite short travel paths. It is planned to equip the new assembly robot with grippers and inter-linking installations from a modular system, in order to further decrease the planning and manufacturing effort. An important aim of the new concept of the Olivetti company is to decrease the cost per robot arm by distributing the proportion of the cost due to the base stand and the controller over a larger number of arms.

The assembly robots by Olivetti are found in industry performing the following operations:

- Assembly of printed circuit boards
- Assembly of colour ribbon cassettes for typewriters
- Assembly of shock absorber components
- Assembly of terminal blocks (shown in Figure 6.1)
- Assembly of electric plugs
- Assembly of feelers for electric typewriters
- Insertion of feelers into the keyboard of a typewriter
- Assembly of piston and connecting rod

Another european assembly robot is the PRAGMA robot by DEA, which, similarly to the Olivetti Serie 3, works in cartesian coordinates. Several examples of this assembly robot, which can be fitted with up to four arms, are also being used in industry, for example for the

- assembly of tie-rod joints in steering assemblies
- assembly of a sealing valve for refrigerators
- assembly of a compressor crank shaft with its bearing.

In 1979 the firm Unimation introduced a family of compact industrial robots which had been developed especially for the performance of assembly tasks. The industrial robot Unimate PUMA 500 and 600 respectively, approximately cover the working space of a human, and are designed for handling weights of up to 2.5 kg. A total of over 200 PUMA industrial robots have been sold, however, they have not yet been used for assembly. Several PUMA-industrial robots are located for experimental purposes in various research institutes and in the laboratories of larger and medium-size companies. In Europe the following planned assembly applications are known:

- Assembly of electrical switches
- Assembly of fanned cables
- Application of adhesives
- Adjustment of headlights with the aid of screwdrivers.

7. Obstacles to Automation

The essential obstacles impeding automation of the pre- and final assembly of components are:

- For the conventional automatic assembly systems the through-put numbers arising are too small, and the number of model variants and types is too large.
- The preparation of the parts (ordering and feeding) is a major effort
- Particularly for final assembly the system structures presently available are frequently unsuitable for automation, since here no flexible interconnection of the automatic and the manual stations is possible via buffers.
- The problem "assembly" comprises, apart from the pure joining process, very many auxiliary functions such as visual inspection, adaptive operations, repair work, which are extremely difficult to automate.
- In final assembly the tolerances of the components make automatic joining very difficult.
- A complicated product design exists which necessitates joining motions in several axes, for which many workpieces come together at one joining place, for which non-positioned joining partners have to be brought into a tightly toleranced assembly position, or which requires an assembly operation within restricted spatial conditions.
- In many cases no exact clamping and location points or faces exist.
- In many cases components have to be handled which are very difficult to feed automatically (tangled parts, slack, easily bent parts,...), and
- Joining techniques with tight tolerances are used with coarsely toleranced components (e.g. dowel pins or fine threads in castings).

If one considers these last-named points in more detail, they may be expressed collectively by the phrase "assembly incompatible design", which indeed is the main impediment towards economically achieving a higher degree of automation in the area of assembly.

Catalogues listing appropriate measures for assembly-compatible product design, with directions regarding "uniform direction of joining" or "chamfering as an aid to joining" are adequately known.

Essential measures for the assembly-compatible design of products can be listed as follows:

A) Standardization of design groups:

The aim must be to restrict the large number of variations of design groups.

B) Standardization of joining points:

Components should, if they indeed have to be shaped differently for different types, at least have the same connection points and assembly method as the neighbouring component. In this way the individual design groups in the different types can be exchanged as often as desired, and hence be assembled on an automat with little re-setting effort.

C) Standardization of assembly direction:

To reduce flexibility requirements of an automatic assembly station a vertical feeding movement from above is to be aimed at as a standardized assembly direction.

D) Joining by motion along a single axis:

This point, together with Point C), lead to a strong reduction of the technical effort of an assembly station.

E) Replacement of screwed connections by locking connections:

Screwing involves numerous individual steps (ordering of screw, setting up, singling out, feeding, checking, locating, start threading, tightening), and requires a high positional accuracy of the assembly parts . Hence automation of the screwing process requires a lot of effort and a high parts quality. Screwed connections are therefore to be avoided, and to be replaced by simple, self-centering lock connections.

F) Avoiding slack, deflecting parts and parts which can become entangled:

Slack, bendable components such as hoses, wires and cables cannot be automatically handled. Such parts are to be replaced by rigid workpieces.

G) Reducing the number of assembly parts:

Whenever possible, individual parts and design groups should be combined.

H) Reducing the extent of the final assembly operation by defining new sub-design-groups:

In the final assembly condition, products are often difficult to handle, caused by a complex contour, or a sensitive or un-toleranced surface. Besides, the largest number of variants naturally occurs at the final assembly stage.
Component dimensions also cause numerous problems. Because of this, as many assembly tasks as possible are to be transfe red from the final assembly stage to the sub-assembly stage within the design groups.

The problem of "assembly-compatible construction" has generally been recognised, but until it penetrates into product construction a lengthy learning process will be necessary. Starting at the student level and continued via further-education measures, engineering designers should be made aware of what consequences even the smallest design changes can have in terms of the effort needed for an automatic assembly station.
For the consistent realization of an assembly-compatible product development with regard to automation, discussions between the developer, designer, production planner and plant installation engineer must be reinforced, especially during the conceptional stage, in order to already identify the problems at that stage which would be impossible to solve, or only possible with a high degree of effort, during continuous and established production.

8. Development trends

Conventional assembly systems (c.f. Figure 1.1) will in future be subjected to increased flexibility demands by the customer, due to market requirements.
For this reason programmable assembly systems will, in the near future, be progressively challenging the position of conventional automatic systems. Thereby, using flexible building block systems, individual conventional stations will be replaced by industrial robots, and completely re-structured assembly islands based on industrial robots will be developed.
These assembly islands will furthermore carry out tasks with cycle times of over one minute, which have hitherto mostly been handled manually (see Figure 1.1).
A parallel development is also expected for the assembly of large parts with a total mass of over 10 kg. In partly automated assembly transfer lines industrial robots are being integrated. Thereby both existing manual workplaces as well as conventional single-purpose automatic stations may be replaced. Furthermore one must consider the application of new inter-linking devices, with the aid of which universally applicable assembly structures may be realized.

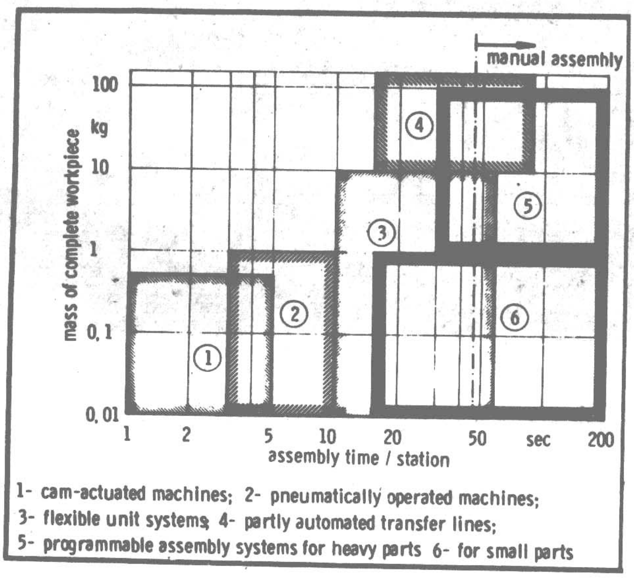

Figure 1.1: Main ranges of application of automated assembly systems.

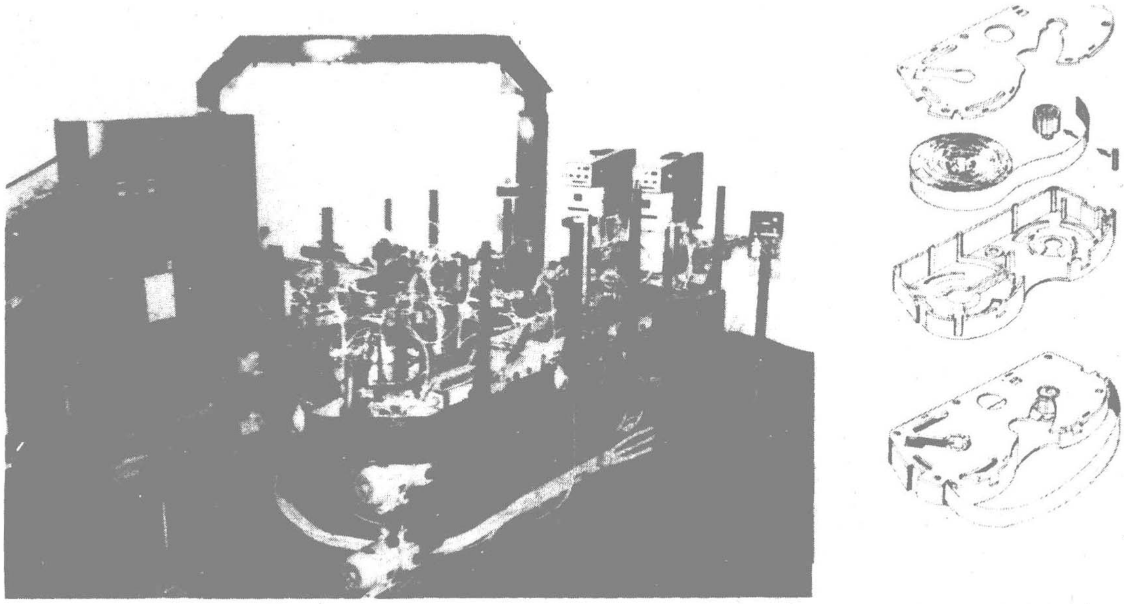

Figure 2.1: Longitudinal transfer assembly automat for typewriter colour ribbons. (OKU-Automatik)

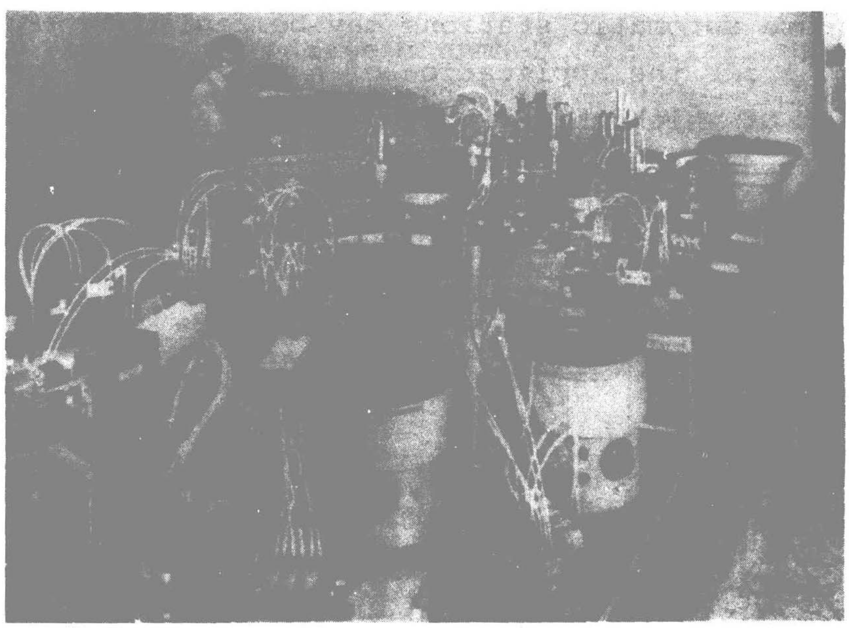

Figure 3.1: Assembly installation for various types of bullets. (Mikrotechnik)