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OBSERVATIONS ON WESTERN EUROPEAN MACHINE TOOL RESEARCH

ALFRED O. SCHMIDT

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Industrial Development Research Program
Institute of Science and Technology
THE UNIVERSITY OF MICHIGAN
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PREFACE

During the summer of 1962 the Institute of Science and Technology conducted an intensive study by personal interview of machine tool builders in Michigan. The purpose of this study was to determine how science and technology might be used more effectively to enhance the growth of the industry in Michigan and in the nation. As the Michigan study was about to start, it was learned that Professor Alfred O. Schmidt, Professor of Mechanical Engineering at Marquette University, Milwaukee, Wisconsin (and formerly Director of Engineering Research at Kearney and Trecker), was planning an extended trip to Europe during the summer and fall of 1962, and would be available for 6-8 weeks to visit firms and research institutes in Europe. A questionnaire was designed for use in Europe to obtain information comparable to that which we planned to obtain from Michigan firms. However, emphasis was placed mainly on obtaining R and D information in Europe.

Dr. Schmidt, a former citizen of Germany, speaks several of the major languages in Europe, and has a large number of personal contacts there. He was thus able to visit firms and institutes in several countries.

Research facilities in France, Spain, Italy, Germany, Denmark, Austria, and England were visited during the months of July, August and September, 1962. Most of the machine tool companies, technical universities, and other laboratories were informed in advance of Dr. Schmidt's visit about the purpose and nature of this survey through letters from the Institute of Science and Technology of The University of Michigan, Ann Arbor. They were assured that the research study was being made by the University for the purposes mentioned above, with state funds, and that, if they so desired, data on individual organizations would be held confidential. With this approach it was possible, within three months, for Dr. Schmidt to interview and corroborate information concerning research activities in seven different countries by visiting 25 large, medium, and small companies engaged solely or partly in the manufacture of metal cutting and forming machine tools. In addition, parallel visits and discussions took place at 15 laboratories which were either in technical universities or established by governments and charged with the task of investigation and research in the field of production and machine tool dynamics.

The detailed findings from this survey are now being incorporated for comparative purposes into the major report on the machine tool industry in Michigan. However, because of broad interest in this information, the present report is now being printed in memorandum form so others may benefit from Dr. Schmidt's observations.

Frank R. Bacon, Jr.
Program Director

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ABSTRACT

This report covers a three-month tour to investigate machine tool research activities in firms and institutes in seven Western European countries including France, Spain, Italy, Germany, Denmark, Austria, and England. The information gathered was to be used for comparative purposes in the Industrial Development Research Program's survey of the Michigan machine tool industry. Visited were 25 firms and 15 institutes that conduct research in production and machine tool dynamics.

1
GENERAL OBSERVATIONS

The increased productivity of Western Europe receives support on the production floor by improved and advanced machine tool designs. Similar European tours that I made in 1949 and 1951 through 12 machine tool producing countries provided a basis of comparison for this 1962 visit.

Currently, the degree of activity in research varies between individual companies. I found considerable differences between nations as well as between companies in a particular country. Much laboratory work classifiable as machine tool research is carried out in Great Britain and Germany. There are thorough-going efforts in France, Italy, Switzerland, Belgium, Holland, Denmark, and Sweden, and noteworthy efforts in Austria and Norway. Spain is beginning to organize research laboratories in the machine tool field at the university level.

In 1949 the opinion most generally expressed in Europe was: "We have to catch up with United States machine tools." Now it is more often stated: "We have caught up in most machine tool areas and we don't need to copy any more." An indication of the status of American machine tools in Europe, as expressed by a Spanish industrialist and engineer engaged in building up the Spanish automotive industry, follows.

> Good European machine tools are equal in quality and performance to American machine tools. American machine tools built in Europe often are not equal to the original American product. We still have to import from the United States of America certain high-precision machine tools, such as gear cutting machines and milling machines with precision positioning. Standard European machine tools are often 30 percent lower in price than similar machines made in the United States of America.

On the basis of visits to machine tool companies and research laboratories as well as discussions with numerous machine tool engineers who were willing to relate their activities, it can be stated that in most cases European machine tool manufacturers, even those employing more than 1000 people, very seldom carry out extensive research programs. All of the large companies have research engineers, many with advanced academic training, who handle specific engineering problems beyond the scope of the design engineers.

Most of the machine tool companies take their research problems to the laboratories of technical universities and are aware of the published findings of university research, which they use as a design guide. Such machine tool research laboratories receive about 25% of their funds from the government, 10% from scientific foundations, 35% from industrial associations, and the rest from individual industrial sponsors. These percentages seem to hold true in general whether the annual laboratory budget is $50,000 or $800,000. Some companies even send their prototype machine tools to university laboratories for evaluation. The Technical University of Vienna has a number of new Hungarian machine tools on loan in their machine tool laboratory for instructional purposes, and these machines were scheduled for replacement by different or new models at the end of the academic year.

Because of the established interrelationship between technical universities and the machine tool industries in the Western European countries, the university professor usually possesses much first-hand knowledge of actual machine tool problems, and most manufacturing industries look upon the technical university as the source of future research engineers. Machine tool builders generally consider the technical university a place for research and sometimes even development work beyond the scope of their own facilities and manpower, or work they want done in an atmosphere removed from the pressures of the factory.

My specific observations from various countries are presented in the following sections.

2
SOME SPECIFIC OBSERVATIONS

I have organized my observations according to the countries visited, which include Great Britain, Germany, Austria, Denmark, Spain, France, and Italy. Although it was physically impossible to visit all machine tool companies, technical universities, and laboratories in these countries, I was able to obtain enough evidence to confirm considerable research activity. Although I visited 25 machine tool companies and 15 laboratories, the information in this report

comes primarily from institutes and technical universities, who were more willing to permit disclosure of information on their research work. I have included an appendix of machine tool research facilities to be found in Western Europe and indicated those institutes and universities that I visited.

2.1. GREAT BRITAIN

The government has a Department of Scientific and Industrial Research to sponsor and coordinate machine tool research in its own laboratories as well as in outside organizations. In September, 1962, over 100 projects were being worked on in seven participating laboratories, such as Birmingham University and the Production Engineering Research Association of Great Britain (PERA). These projects included investigations concerning the performance of machine tools, mechanisms and sliders, metal cutting, vibrations, metal forming, servo-mechanisms, positioning systems, bearings, and unconventional machining processes.

However, the projects sponsored by the Department of Scientific and Industrial Research were only a part of the research work carried out in the co-operating laboratories.

2.1.1. UNIVERSITY OF BIRMINGHAM. Machine tool research at the University of Birmingham was done in the Mechanical Engineering Department of their Institute for Advanced Studies in Engineering Sciences, Division for Machine Tools, Materials and Management (Director: Professor Tobias). A summary lists 16 major projects in three fields of machine tool dynamics, forming and shaping techniques, metallurgy and metal cutting, computers, and automation research. Cooperation came as well from the departments of Metallurgy, Engineering Production, Chemical and Electrical Engineering. Research in progress included: cutting with oscillating tools (Figure 1), dynamic stability investigations (Figure 2), acceptance tests of machine tools, torsional vibrations in machine tool drives, optimum design of machine tool structures, development of machines for high energy forming of materials, and economics and accuracy in machine tool utilization.

Eighty percent of these research activities dealt with fundamental understanding of new and existing metal removal processes. The rest of the research projects were concerned with design and development of new machine tools and machine auxiliaries. The research staff includes eight leaders with Ph.D. degrees, 25 graduate students, ten graduate institute technicians, and 40 mechanics with long years of industrial experience. Total salary expenditure was about $140,000 a year in 1962. About one-half of the operating funds came from the British government, and the rest from industrial sponsors.

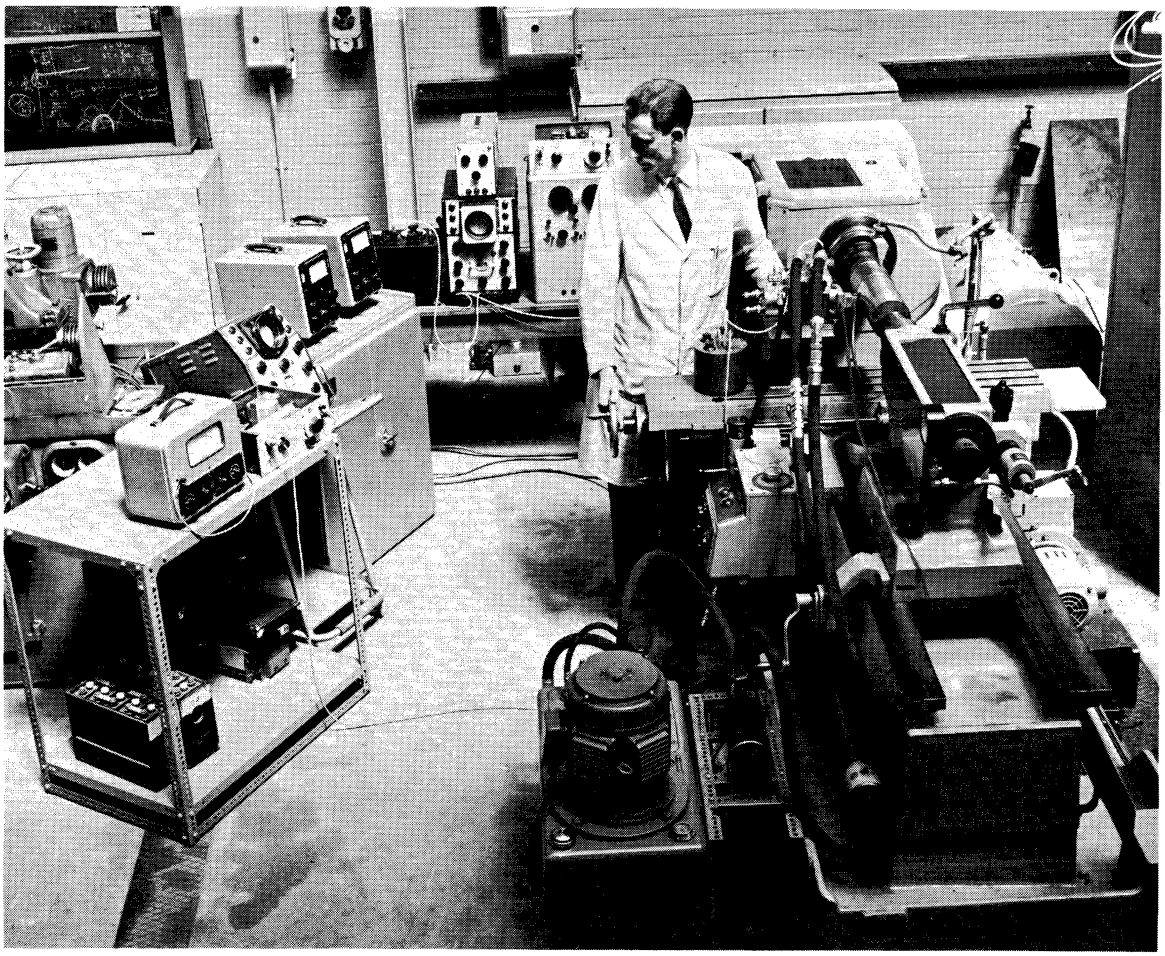

FIGURE 1. A GENERAL VIEW OF THE LABORATORY SETUP FOR CUTTING WITH AN OSCILLATING TOOL AT THE DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF BIRMINGHAM

The British Machine Tool Trades Association has sponsored over 30 scholarships since 1959, mainly in the field of machine tool design at the College of Science and Technology in Manchester. The Machine Tool Industry Research Association, Manchester, maintains a close relationship with the Institute for Advanced Studies in Engineering Sciences at Birmingham University and has underwritten several research projects there as well as at seven other universities.

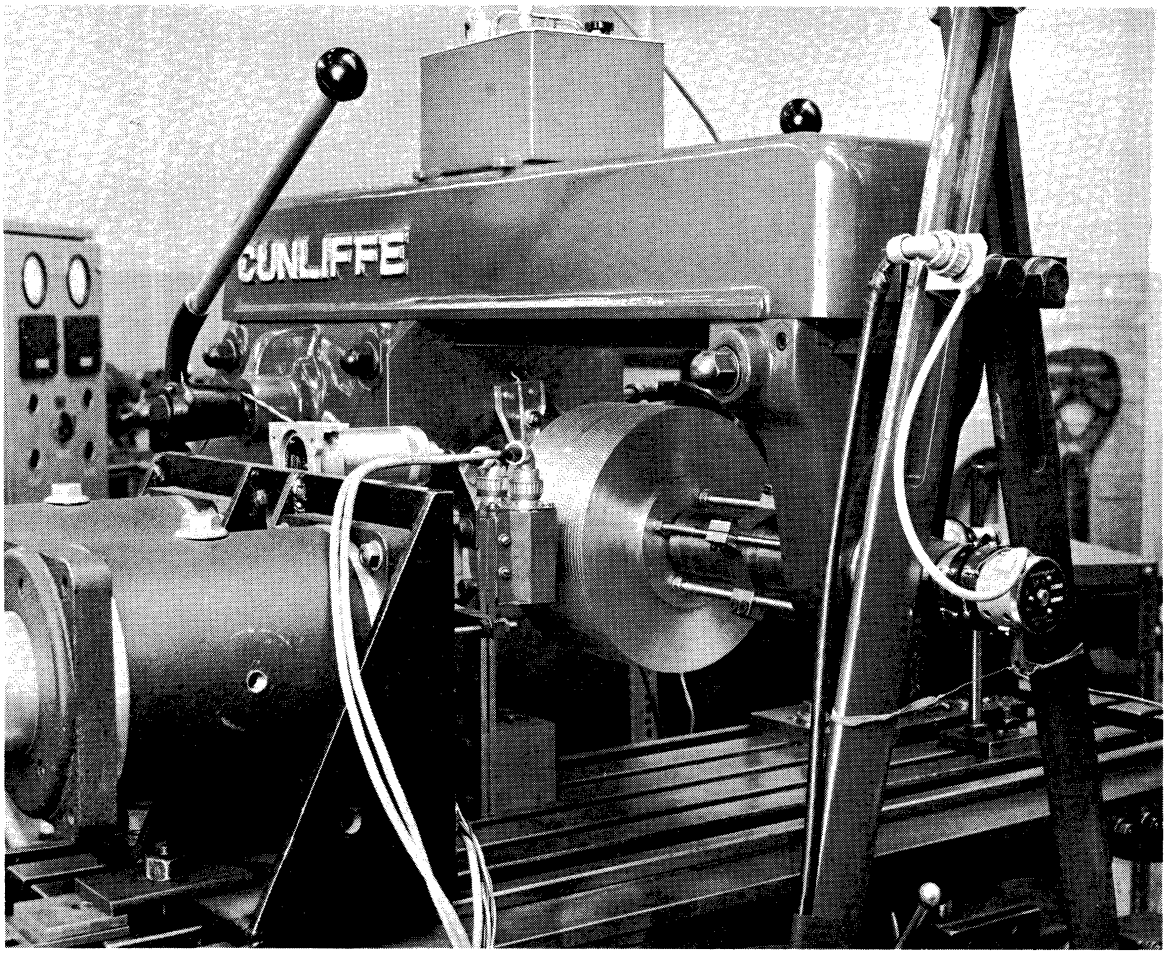

FIGURE 2. DYNAMIC METAL CUTTING STUDY REGARDING MACHINE TOOL CHATTER VIBRATIONS. University of Birmingham.

Every two years Birmingham University holds an international machine tool design and research conference which alternates with a similar conference at the Manchester College of Science and Technology. The October 1962 conference at Birmingham was attended by over 400 engineers from more than 12 countries and was a result of the efforts, made especially in Europe, to provide a scientific basis for what is generally considered shop practice.

Ten foreign countries, including Japan, were represented by speakers dealing with research, design, and production in the field of metal processing and machine tools. The conference emphasized that engineering is applied science and, besides brains, also requires trained eyes and skilled hands for optimum realization.

Lord Hailsham, the British Minister for Science, took part in the conference and spoke several times about the role of engineering research in a society both wanting and needing to advance. He stated that "pure science" has always flourished in Great Britain but that the country was now paying dearly for the past reluctance of the "scientist" to concern himself with the application of scientific discoveries. The Birmingham conference served to acquaint the "scientist" with the opportunities in machine tool engineering for further research and the use of his method to stimulate a vital field so necessary for progress. For the practitioner it provided the opportunities of finding help for his numerous problems by the use of a scientific approach.

Representatives of various educational institutions decided in informal discussions that teaching in machine tool engineering cannot rely only on science, just as the education of a musician, who is also expected to play in an orchestra, cannot be completed by the teaching of acoustics only.

There was also recognition that countries like Poland, China, and Hungary today have sizable machine tool industries in competition with Great Britain in world markets. Before World War II these countries had to import almost all their production machinery. After World War II they started their rebuilding of industry with research laboratories which still operate and provide data for new manufacturing processes and for the design of new machine tools. Incidentally, a conference of the magnitude of the one in Birmingham has not taken place in the U. S. during the last decade.

2.1.2. STAVELY RESEARCH GROUP. A consolidated endeavor by a number of British machine tool builders resulted in the Stavely Group Research Department (Research Director: Dr. Frost-Smith). Companies which organized this laboratory in 1956 include George Richards & Company Ltd., James Archdale & Company Ltd., Cunliffe & Croom Ltd., J. H. Shand Ltd., W. H. Smith & Company Ltd., Tilghmans Ltd., and Standard Modern Tool Company Ltd. in Canada. The Stavely Group's research work in the fields of mechanical engineering, control systems and electronics has dealt with the needed improvements in machine tools to adapt them to computer control (Figures 3 and 4), and with vibrations, machine tool hydraulics, and structures (Figure 5). Their research engineers and supporting staff maintain close contact with other groups active in machine tool research.

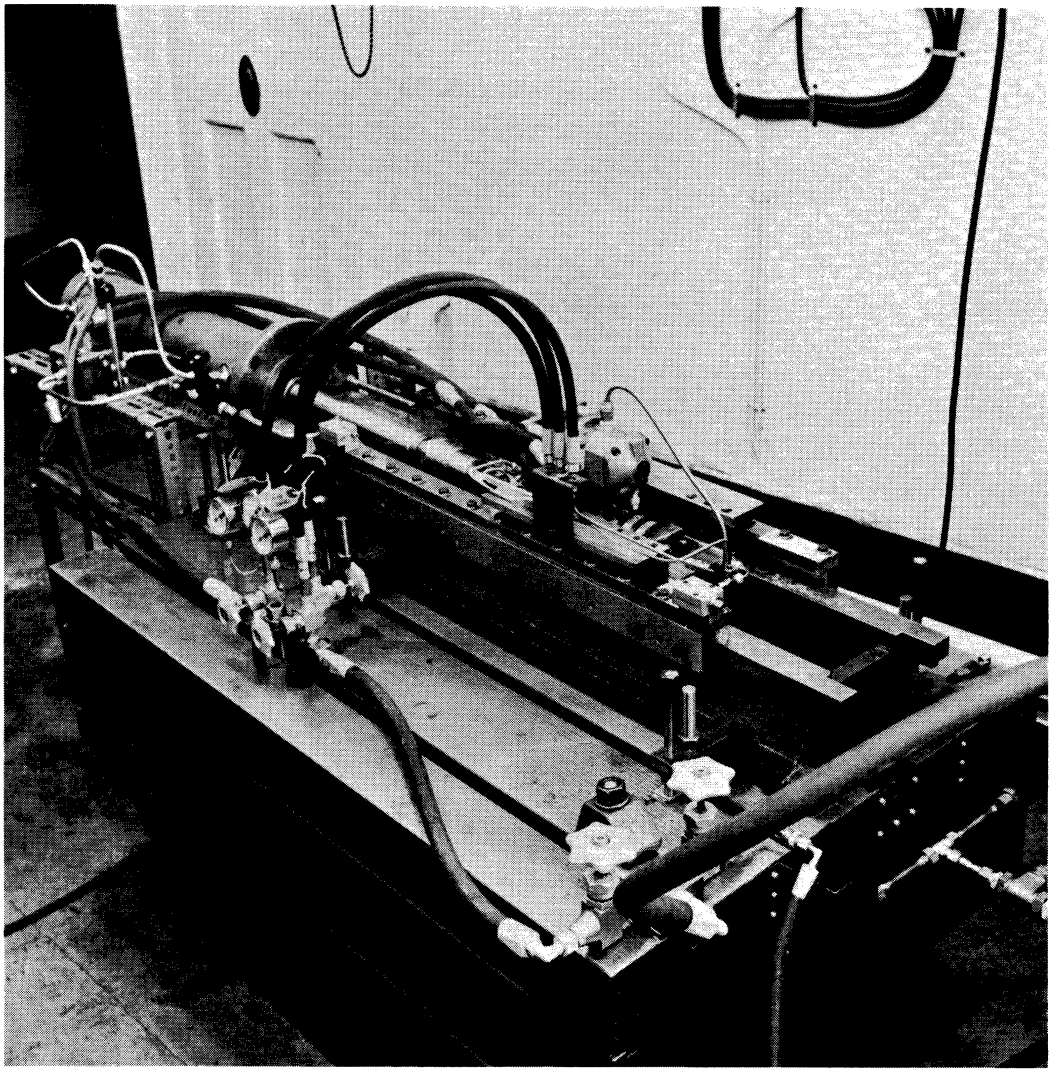

FIGURE 3. MEASURING THE STIFFNESS OF A MACHINE TOOL FEED MECHANISM, STAVELY RESEARCH. Courtesy of Machinery, London, England.

2.1.3. PRODUCTION ENGINEERING RESEARCH ASSOCIATION (PERA). A joint effort of British industries resulted in the Production Engineering Research Association (PERA) of Great Britain (Research Director: Dr. Galloway), a large organization with several extensive laboratories at Melton Mowbray, Leicestershire. Although PERA deals with all types of industrial research, a good part of the total effort has been for British machine tool builders. Some of the work carried out has dealt with flat-slider friction, machine tool vibrations and rigidity, temperatures in spindle bearings, and measurements and control of factors influencing machine tool performance with the aim of establishing more adequate specifications for machine tools.

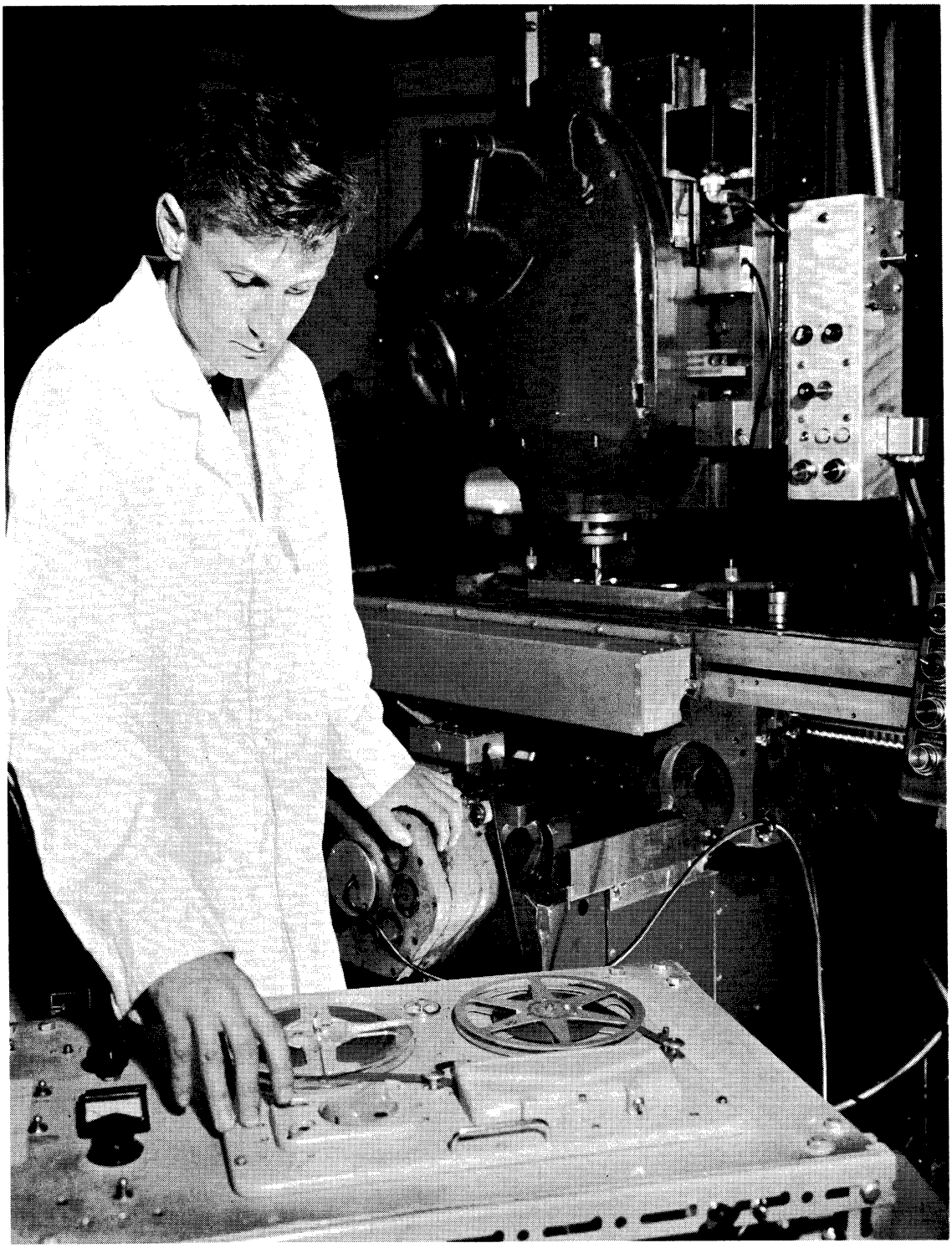

FIGURE 4. INVESTIGATION REGARDING THE USE OF MAGNETIC TAPE FOR MACHINE TOOL CONTROL. Stavely Research.

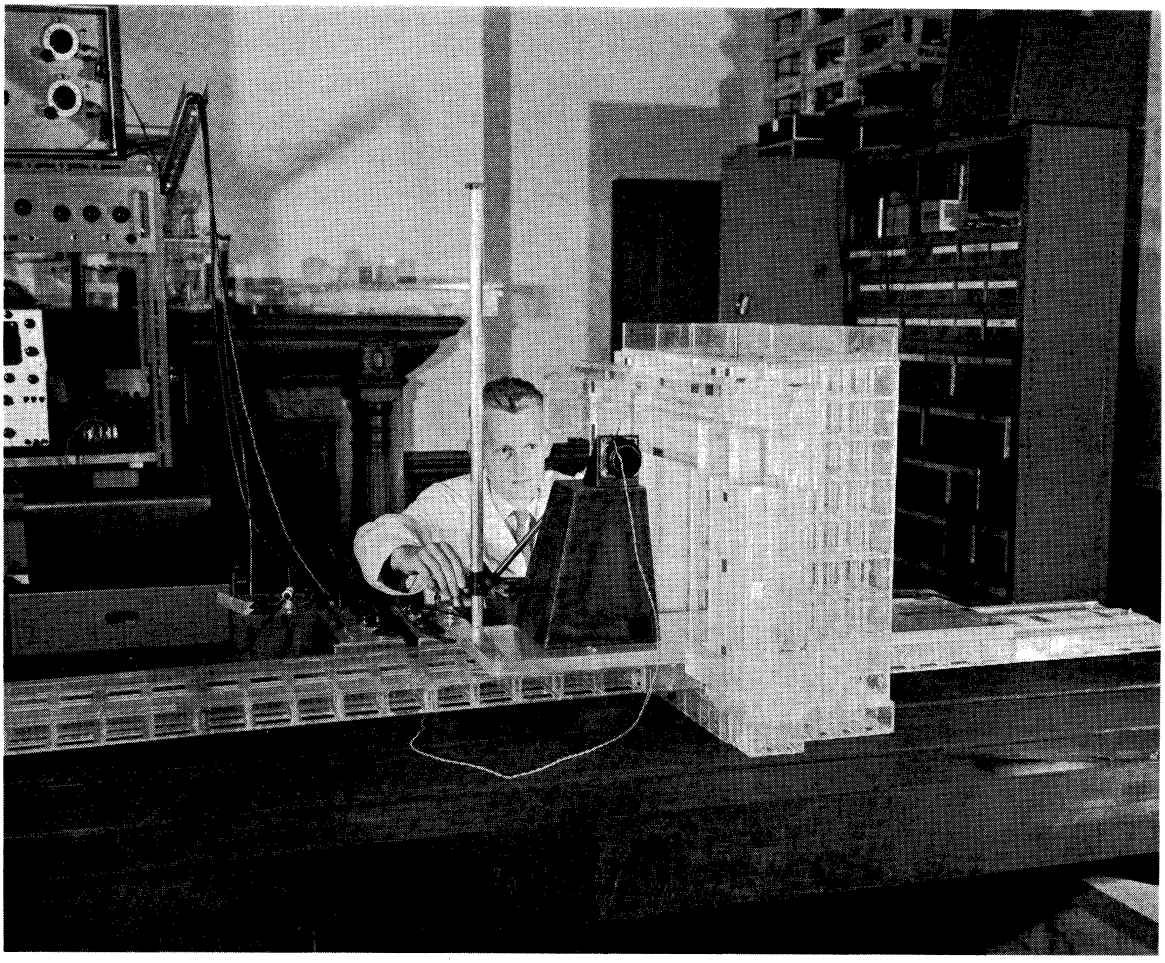

FIGURE 5. PLASTIC MODELS FOR DYNAMIC MACHINE TOOL STRUCTURE SYNTHESIS. Stavely Research.

2.1.4. ADVANCED STUDIES IN TECHNOLOGY. The British government selected nine technical colleges and granted them the status of Colleges of Advanced Technology. A major objective of these colleges is to develop research and graduate studies in the field of production technology. They maintain close relations with industry and for their advanced degrees (master's and Ph.D. level) the subject matter for the thesis is usually suggested by industry. The instructional staff is appointed from among people who have practiced engineering successfully for a number of years in industry. The Northampton College of Advanced Technology in London has a department of Production Technology (Director: Mr. Williams) as well as a department

of Instrument and Control Engineering (Director: Mr. Finkelstein) with laboratory facilities and equipment adequate for advanced work in machine tool studies. The government fosters this development by awarding research fellowships to graduate engineers.

2.2. GERMANY

2.2.1. BACKGROUND. Although a good part of the German machine tool capacity was located within the Soviet Zone, many firms from that section of the country have been re-established in Western Germany. A tradition of metal cutting and machine tool research in Germany gave impetus to the machine tool industry after World War II. When judging German machine tools, one should bear in mind that many of the German factories were bombed out during World War II or were completely dismantled afterwards and in several cases did not produce again until 1950, when most of the post-war restrictions were removed.

Each of the German machine tool factories was concerned about certain engineering problems which could not be handled by their designers. It is an accepted practice in the larger companies to have well trained research engineers on the staff and also to work with the machine tool laboratories of the technical universities. All technical universities have machine tool research laboratories and staffs ranging in size from four to fifty research engineers plus supporting personnel.

The production engineering division of the German Engineering Society (VDI) (Manager: Mr. K. Engelhard) also sponsors research. A new field or a new production problem considered serious enough will be proposed as a research project for a technical university. The society will then contact the federal ministry for economics or a ministry of a German state for research funds. If the work concerns an industrial survey regarding practices or improvement of technology, then the funds are usually provided by industry. The engineering society also edits particular research reports in a form that can be used by the production engineer. How completely this work is organized by the production engineering division can be appreciated when it is realized that the division has 15 groups and annually sponsors 200 committee meetings, 40 round table discussions dealing with specific production problems, and 500 general production engineering meetings which are open to the technical public. It should also be mentioned that this activity has been going on for over 40 years.

West Germany has, at present, eight technical universities, all of which carry on machine tool research. The emphasis in these activities varies from one institute to the next. Some of their work has had world-wide significance (e.g., machine tool test cards which were first developed by Professor Schlesinger at the Technical University of Berlin and are now incorporated in many test procedures for machine tools in numerous countries).

Most of the laboratories visited at German technical universities were well housed and equipped, especially those that had been completely destroyed during World War II.

Research work is carried out in each institute under industrial sponsorship or is supported by foundation funds, government grants, or awards from industrial associations. Many production and machine tool engineering problems serve as the basis for a thesis on the master's or doctor's degree level. There is a good supply of candidates available for this kind of research work. After completing the projects successfully the young researchers often go to work for their industrial sponsors who may be either machine tool builders or, very often, the users of machine tools (e.g., metal working manufacturing plants).

2.2.2. TECHNICAL UNIVERSITY AT BRUNSWICK. The Technical University in Braunschweig has an Institute for Machine Tools and Production Technology (Director: Professor G. Pahlitzsch). It is housed in a new building with over 20,000 square feet of floor space (Figure 6). Although not the largest laboratory, it performs generally successful research, a result of well defined projects. The work, conducted by 15 research engineers, includes comparison of synthetic and natural diamonds in the grinding of metals (Figure 7), sawing and grinding of glass, grinding of ceramic tool tips, spray lubrication, belt grinding, and centrifugal forces acting on a rotating chuck (Figure 8). For several years this laboratory carried out investigation and designed equipment for finish rolling of cylindrical workpieces (Figure 9). Experimental combination of high-frequency lapping and electrolytic action have been in progress for the last two

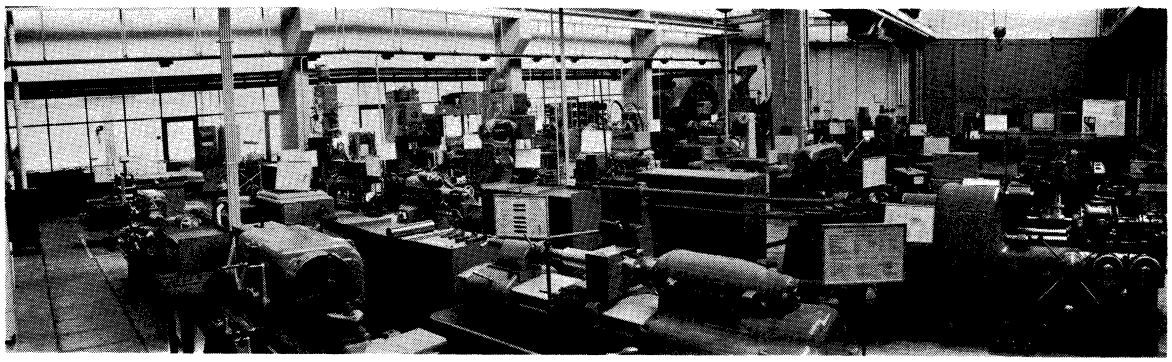

FIGURE 6. MAIN FLOOR OF THE MACHINE TOOL LABORATORY AT THE TECHNICAL UNIVERSITY. BRUNSWICK.

years with promising results (Figure 10). This machine tool institute also has the only extensive wood working laboratory in existence in a technical university in Western Germany (Figure 11). Laboratory equipment is valued at about $750,000. Additional research facilities include climate and sound control chambers with measuring instrumentation, precision measurement laboratories including electron-microscopes, and a photographic laboratory, as well as an instrument shop for the building of experimental equipment. During the last 25 years the degree of Doctor of Engineering was earned by 44 graduate students working on research projects in the institute.

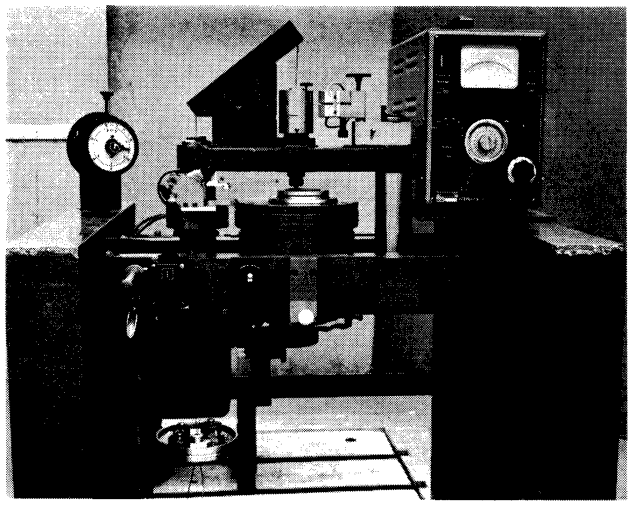

FIGURE 7. TEST ARRANGEMENT FOR THE INVESTIGATION OF GRINDING GRITS. Brunswick.

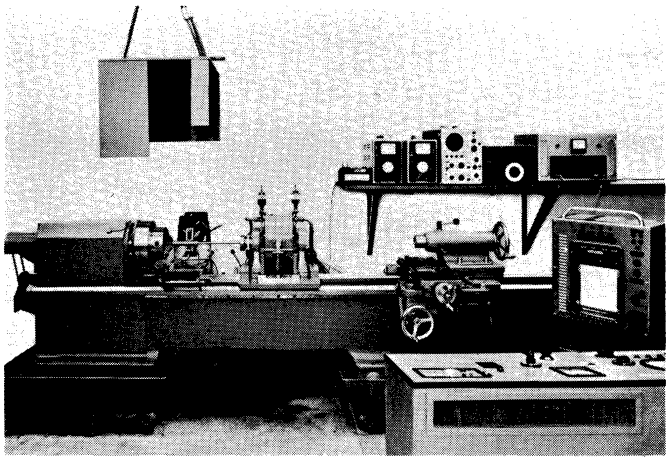

FIGURE 8. INVESTIGATION OF THE BEHAVIOR OF THREE-JAW CHUCKS AT HIGH SPEEDS, MAXIMUM OBTAINABLE 8300 rpm BY LEONARD DRIVE. Brunswick.

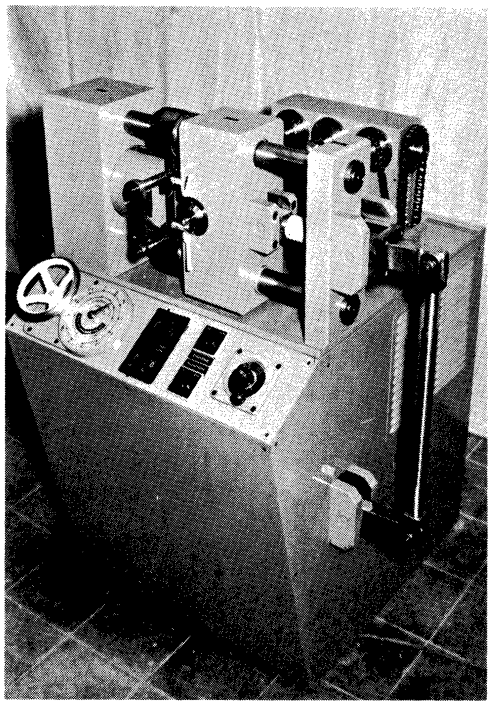

FIGURE 9. DETERMINATION OF SURFACE FINISHES OBTAINABLE BY COLD ROLLING. Present tests concern dimensional accuracy of cylindrical parts which have been rough turned. Brunswick.

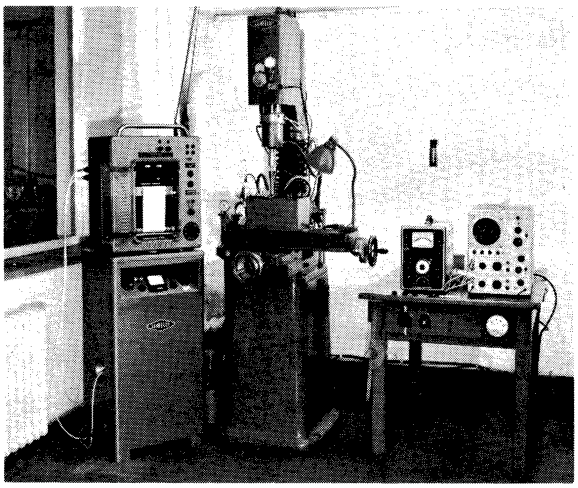

FIGURE 10. LAPPING RESEARCH WITH HIGH FREQUENCY VIBRATIONS. Brunswick.

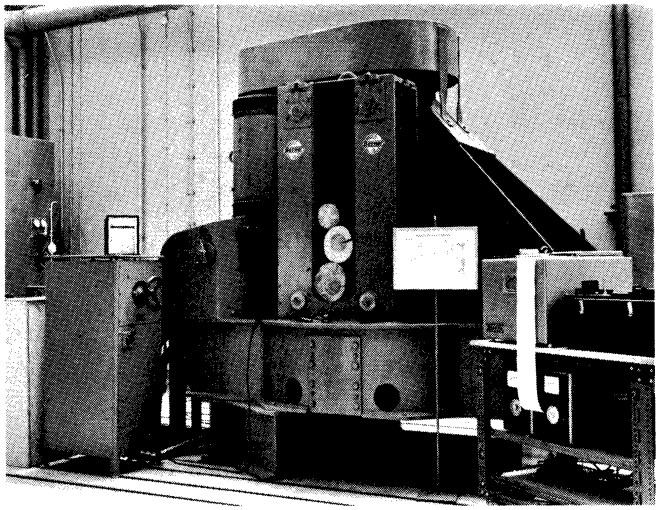

FIGURE 11. EXPERIMENTAL MACHINE FOR MAKING WOOD CHIPS USED FOR FIBRE-BOARD. Investigation concerns chip formation relative to cutting conditions which will produce chips for optimum board quality. Brunswick.

2.2.3. TECHNICAL UNIVERSITY AT HANOVER. The nearby Technical University in Hanover has an Institute of Production Engineering (Director: Professor W. Osenberg) which has operated since 1946. It has two divisions, one for metal cutting and the other for chipless forming. Altogether, 16 research engineers and supporting staff work on projects of ultrasonic machining, explosive forming, metal spinning, grinding, sand blasting, electromagnetic clutches, and stamping and rolling of shapes.

2.2.4. TECHNICAL UNIVERSITY AT MUNICH. The Institute for Machine Tools at the Technical University of Munich (Director: Professor F. Eisele) has a widespread reputation as a center for vibration studies, especially in the machine tool field. Twenty research engineers and a supporting staff investigate the fundamental mechanisms of turning, boring, milling, and broaching operations including chatter and vibration phenomena. Additional research efforts concern flat-slider bearings and lubrication, leadscrews, hydraulic feed drives, speed and power controls, and comparative studies of welded and cast structures. Supporting research equipment includes a precision measurement laboratory (Figure 12) and metallurgical as well as chemical facilities (Figure 13). Every two years the institute organizes a machine tool conference which attracts approximately 1000 participants from all parts of the world.

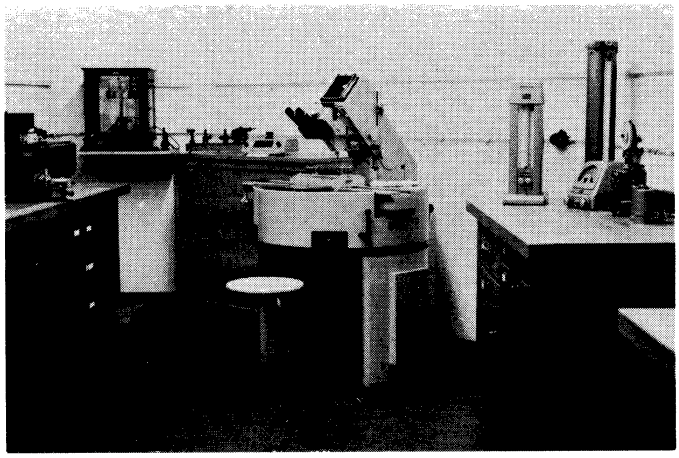

FIGURE 12. PRECISION MEASUREMENT EQUIPMENT AT THE MACHINE TOOL LABORATORY AT THE TECHNICAL UNIVERSITY, MUNICH. In the center is a universal measuring microscope made by Zeiss.

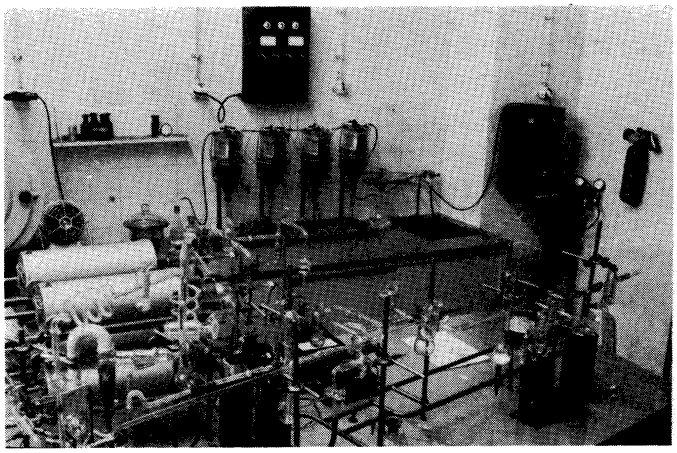

FIGURE 13. LABORATORY SETUP FOR THE ISOLATION OF OXIDE INCLUSIONS IN STEEL WORK PIECES. This investigation was carried out to determine the effect on tool life. Munich.

2.2.5. TECHNICAL UNIVERSITY AT BERLIN. The Technical University of Berlin has an Institute for Machine Tools and Production Technology (Director: Professor H. Schallbroch) which has been in existence since 1910. Test cards for machine tools were developed here many years ago by Professor Georg Schlesinger. A staff of four research engineers works on

problems in metal cutting and machine tool vibrations. Work in these projects is often assigned to graduate students. The institute also evaluates new prototype machine tools and factory organizations.

2.2.6. TECHNICAL UNIVERSITY AT AACHEN. The largest machine tool institute is at the Technical University in Aachen (Director: Professor H. Opitz) (Figure 14). This institute also arranges an international machine tool conference every second year. The staff is comprised of 230 people, among whom there are 50 research engineers and 100 graduate assistants, the latter working half time. The institute, founded in 1910, covers in its work all phases of machine tool research, including evaluation of control systems and components, computer technology, and lubrication. The research findings are reported at the biennial machine tool conference and at numerous German and international engineering meetings. The institute is organized in three general sections: metal cutting, controls, and structures.

FIGURE 14. MAIN SECTION OF THE MACHINE TOOL LABORATORY OF THE TECHNICAL UNIVERSITY AT AACHEN, WESTERN GERMANY. In 1945 this building had been bombed with little more than the foundation left.

Investigations carried on in the various sections, each headed by a chief engineer, are listed below; they indicate research done generally in technical universities.

Effects of workpiece materials and properties of tool materials in turning, milling, boring, reaming, and planing.

Finish machining and workpiece surface conditions in grinding, honing, turning, and boring.

Various methods of tool life testing and comparative evaluation of short time tests.

Determination of machinability of various batches of the same type of workpiece material.

Influence upon machinability of various degrees of cold rolling of steel.

Effect of microstructure and chemical analysis upon tool life and tool forces.

Evaluation of cutter entrance conditions in milling, and preparation of data for shop use.

Effect of microstructure and coolants upon surface finish in broaching.

Comparative evaluation of ceramic tools.

Machinability of light metals.

Evaluation of grinding wheel wear and surface finish obtained when grinding at high speeds.

Determination of fundamental factors in grinding (e.g., the number of effective grains in a wheel, and investigation of the hardness and structure of specific grinding wheels).

Investigation of the amount of material removed, surface quality, and tool wear in honing.

Analysis of the economics of various finishing processes, effects of tool shape and wear upon dimensions and surface finish.

Workpiece tolerances and shape accuracy.

Relationship between surface specifications and surface finish measurements.

Fundamentals of spark erosion. Effects of impulse characteristics, workpiece and dielectric materials upon metal removal, tool wear, and surface finish.

Analysis of electrical circuits for electrical discharge machinery.

Accuracy of electro-discharge machining relative to die making and finishes obtainable.

Development and investigation of new generators.

Fundamentals of electrolytic machining, effect of workpiece material, and electrolyte when making internal shapes.

Application of electrolytic grinding to profiles and tool grinding.

Time of reaction of electro-magnetic clutches.

Step motors.

Switches and pneumatic measuring devices for the development of machine tool controls with various types of tapes.

Pressure and flow characteristics and stability under dynamic conditions of hydraulic control valves.

Characteristics of hydraulic motors for machine tool use.

Present state and future development trends in hydraulic copying devices and their control systems.

Static and dynamic characteristics of columns, beds, spindle bearings, and the combinations of these elements.

Investigations of a heavy milling and planing machine, roll lathe, and large boring machine.

Frictional wear of machine tool guideways.

Investigation of gear cutting machinery carried out by analyzing the effects of accuracy upon the performance of gear drives. (Checking various types of gear making machinery such as gear milling machines, gear shapers, and gear grinders.)

Development of measuring devices for checking accuracies in gears.

Determining the kinematic accuracy of assembled gear drives.

Lapping of gear drives, in particular drives for roll polishing machines and cable making equipment where deviations in the drive are responsible for variations of thickness in the cable.

Means and ways to measure life of gear drives, load carrying capacity of non-hardened gears, and strength of the tooth roots.

X-ray investigations concerned with the effects on gear life of hardening and radii at the roots of gear teeth.

Gear noise and its causes relative to gear design and manufacture, gear housing, and their acoustics.

Lapping of gear drives with hardened and non-hardened gears in sizes up to 28,000 hp.

Determination of cutting forces and tool wear in various types of gear making and its effects upon the surface finish of teeth.

2.3. AUSTRIA

Several machine tool builders in Austria have a good reputation and a good export market.

2.3.1. TECHNICAL UNIVERSITY AT VIENNA. The technical university in Vienna (Director: Professor Tschirf) uses its extensive machine tool laboratories for instruction as well as research. Several of the machine tools in the laboratory were on loan from such countries as France, England, Russia, and Hungary. Research projects at the present time include magnetic tape controls for lathes, an automatic hardness tester, an ultrasonic boring machine, interchangeability of precision parts, and the mechanics of metal deformation.

2.3.2. THE AUSTRIAN SOCIETY FOR THE PROMOTION OF PRODUCTION RESEARCH AND TRAINING. This organization has furnished a building which has been newly equipped with lecture halls, laboratory rooms, and a library. Problems investigated here concern Austrian machine tool productivity and factory organization. They follow closely developments in Switzerland and the U.S. in determining the direction of their own research programs.

2.4. DENMARK

The Danish machine tool industry has contributed significantly to the change in the national economy of Denmark. Although agriculture was the main source of income for the population before World War II, industry now is.

Danish machine tool companies, generally small by U.S. standards, produce machine tools of good quality that are accepted as such all over the world. Development work is carried out by their own design engineers: the technical university is consulted on more difficult problems.

2.4.1. TECHNICAL UNIVERSITY AT COPENHAGEN. The staff of the machine tool and design laboratories of the Technical University of Copenhagen (Directors: Professors K. V. Olsen and Jeppesen) numbers over 50 people, among whom are 12 research engineers and technicians, 18 mechanics, and 12 machine shop apprentices. Their major activities concern metal cutting, electro-discharge processes, machine tool bearings (Figure 15), screws, feed drives, and hydraulic controls. Government funds provide the main income, which is augmented by sponsorship of special projects by industry.

The Technical University in Copenhagen, with a long tradition of service to industry, divides its activity in the machine tool field into three parts: (1) machine tool research and general machine technology, (2) product development and engineering design, and (3) foundry technology. More than $100 million has been appropriated for the new technical university with enlarged machine tool laboratories currently being build on the outskirts of Copenhagen.

2.4.2. DANISH MACHINE TOOLS IN GENERAL. A machine tool manufacturer in Denmark who employs more than 50 people is considered a large machine tool builder. The tendency of the Danish machine tool industry to specialize allows firms to remain competitive in the world market with their precision machines. Two Danish machine tool manufacturers who make special grinding and honing machines, used mainly in automotive repair shops, produce about 89% of the total world production in this type of equipment.

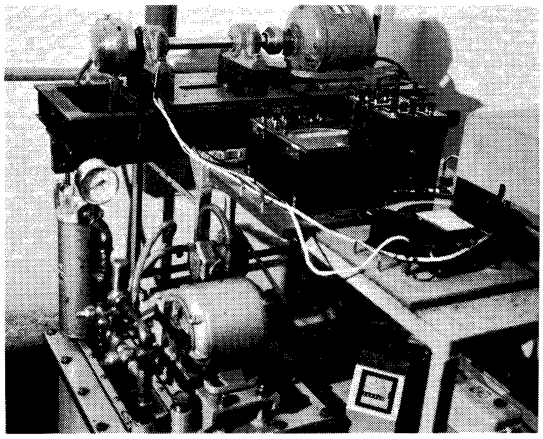

FIGURE 15. EXTENDED LOAD, TIME AND TEMPERATURE TESTS OF TWO-INCH JOURNAL BEARINGS RUNNING AT 2800 rpm. The bearing material is bronze, 2.4 inches long, and has four contacts with a hardened steel shaft. Technical University, Copenhagen, Denmark.

When inspecting Danish metalworking shops one can see machine tools from all over the world. The Danes have no difficulty in making British, U.S., French, German, Italian, Czech, and Russian machines perform to the same standards.

2.5. SPAIN

Spain has more than 200 firms, mostly very small, which may be classified as machine tool builders. They generally supply the ordinary machine tool requirements of Spanish industries. However, some Spanish machine tools (e.g., drill presses) are exported even to Germany. South America has been their main overseas customer. Although the skill of the Spanish mechanic is high, all the industries, and principally the machine tool industry, suffer from a lack of consistent quality of workpiece materials. The need for machines of high quality and specialized production is met by importation, mainly from Western Europe or the U.S.

Spanish machine tool builders conduct very little research; some have obtained licenses from abroad to modernize their machine tool designs.

There are three new university level engineering schools in Spain (Escuela Superior de Ingenieros Industriales) currently working with industrial production and machine tool problems.

These schools, located in Bilbao, Madrid, and Barcelona, with their new and modern laboratories (including those for machine tools) are equipped mainly with German machinery.

The Centro de Estudios Tecnicos de Automocion in Madrid (Director: Señor Ricart) has been charged by the Spanish government with studying the possibilties of raising the level of Spanish machine tool production.

2.6. FRANCE

2.6.1. LABORATOIRE CENTRAL DE L'ARMEMENT. Machine tool and metal cutting research in France has been carried out on a considerable scale since 1945 by the Laboratoire Central de l'Armement in Arcueil, a suburb of Paris. The Section de Mécanique Industrielle et d'Essais de Machine-Outil (Director: Mr. Weill) has well equipped and well staffed machine tool research and metal cutting laboratories employing 5 research engineers, 5 research technicians, and 18 laboratory technicians. The program of research and experimental projects includes static and dynamic precision of machine tools; theoretical and experimental studies of metal cutting; including electro-chemical and electro-discharge machining, tool materials, lubrication, and optimizing machining conditions with digital computers. Although these laboratories primarily serve the arsenals and factories of the French government, they also work on general industrial machine tool and machinability problems.

2.6.2. CENTRE D'ETUDES ET DE RECHERCHE DE LA MACHINE OUTIL. With the great progress made in French machine tool design and by French machine tool builders during the last ten years has come the recognition that definite technical problems confront the machine tool industry today which can be handled effectively by a laboratory specializing in machine tool research. The Centre D'Etudes et de Recherche de la Machine Outil, in St. Ouen near Paris, was founded in 1962 as a central research laboratory for and by the French machine tool builders (Director: Mr. Lombard). Although at present only a director and several engineers have been appointed, they already have a building and some equipment and have started work on certain phases of several extensive projects (e.g., standardization of d-c motor speed controls, hydrostatic way bearings, and processes for stabilizing die casting dimensions).

2.6.3. RÉGIE RENAULT. Among French machine tool manufacturers, one of the largest is the Régie Renault. The machine tool division, started by the automobile manufactuerer after World War II, is now one of the recognized leaders in the production of special machine tools (Director: Mr. Bezier). Transfer-type machines of unit design are built on special orders from all corners of the world. They also have a plant in Great Britain — Renault Machine Tools (U.K.)

Ltd., Shrewsbury. Their one built-in customer, the Renault Automotive plant, produces over 500,000 cars and trucks per year. However, even there a Renault machine tool is ordered only if it is competitive with other makes. New developments and prototype machines are run under actual production setups, and the laboratories of the automotive works and their engineers are readily available when needed.

One of their latest developments, a 13-station transfer machine for balancing engine crankshafts, is in operation in their own automobile plant in Billancourt near Paris. The output is 100 to 120 balanced crankshafts per hour. Out-of-balance of the crankshafts is determined in two planes, and the necessary calculations are made by a computer which relays information to several workstations that make corrective milling cuts of definite depth and direction.

A numerically controlled 5-hp drill press of Renault's own design has been in operation for several years in the machine tool plant. The machine is used mainly for drilling, boring, spotfacing, and tapping operations on platen-type fixtures with an accuracy of 0.0004 inch. A paper tape, 90 mm (3 9/16 inches) in width, is used. The control equipment which is transistorized, was designed and built by Renault. A larger machine with an 8-hp spindle drive is currently being built.

2.6.4. ERNAULT-SOMUA. Another significant development in the French machine tool industry also occurred in 1962 with the founding of Ernault-Somua, which combined six French machine tool companies employing 2400 people altogether. Their products include large and small lathes, milling machines, and turret lathes. This new combine has its own sales organization, AFMO (Association Français des Machines Outils). Ernault-Somua has in fact become part of the Schneider-Creuzot combine, the largest French industrial organization; it comprises over 3000 large and small factories. Before 1962 the Schneider-Creuzot organization included only one machine tool factory employing 400 people making boring machines, planers, and drill presses.

2.7. ITALY

Great progress has been made in the design and quality of workmanship in Italian machine tools as compared with the machines produced 10 or 12 years ago. Most of the machine tool factories are in the industrial north. Two main centers, in Turin and Milan, have polytechnical institutes as well as a variety of large industries. The individual Italian machine tool factory does little that could be called research. It usually has, however, besides competent designers,

a number of engineers with higher academic degrees who deal with more fundamental questions. Research problems are usually referred to the polytechnical institutes which have machine tool laboratories.

2.7.1. ASVILMET AND SVIMU. The Italian machine tool builders, with the support of the National Research Council (CNR), have organized two laboratories to serve their industry. One in Turin, named ASVILMET,[1] is intended to concentrate on metal cutting research; the other one, in Milan, SVIMU,[2] will be concerned with machine tool structures. Although there is already a fine multi-story laboratory building in Turin, the actual work in progress is handicapped by a shortage of qualified personnel. However, various metal cutting research projects are worked on in the laboratories of the Istituto Politecnico and problems in dynamics are handled at the Istituto Dinamometrico. Both institutes, located in Turin, are state supported, but also carry on work sponsored by industry.

2.7.2. POLYTECHNIC INSTITUTE OF TURIN. The machine tool laboratory of the Polytechnic Institute of Turin (Director: Professor Micheletti) has a small number of research engineers and technicians working on projects, some of them sponsored by industry. Most of the work, directed toward the understanding of scientific principles, deals with surface roughness, plastic forming of sheet steel, metal cutting temperature determinations, tool forces (Figures 16, 17), and automatic as well as hydraulic machine tool controls.

2.7.3. ISTITUTO DINAMOMETRICO ITALIANO. The Istituto Dinamometrico Italiano (Director: Professor Bray), a research and teaching laboratory founded by the National Research Council of Italy in 1954, has at present a staff of twelve, of whom seven are research engineers. Current work of interest to machine tool builders includes stress anaysis of new metal forming processes (Figure 18). Other projects deal with the determination of residual stresses in machined and heat-treated parts, strain analysis on models, measurement of gear stresses, calibration of vibration pick-up devices, and determination of loads and accuracy of hydraulic jacks.

2.7.4. FIAT. The largest engineering complex in Italy is Fiat, which, besides cars, makes locomotives, diesel engines, and ball bearings. The company's wide use of precision machine tools helped significantly the development of the Italian machine tool industry. Besides making

[1] Association for the Development of Metal Cutting.

[2] Society for the Development of Machine Tools.

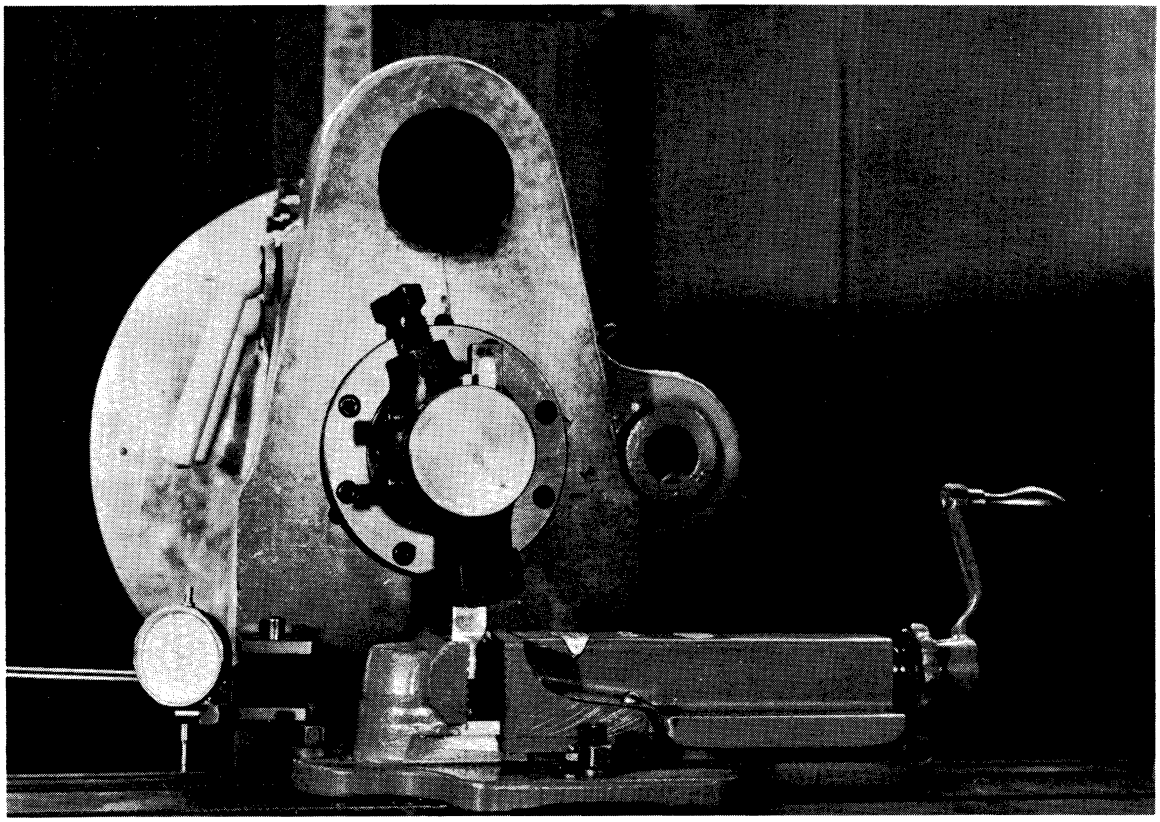

FIGURE 16. MILLING MACHINE ADAPTED FOR PENDULUM HAMMER INVESTIGATION REGARDING CUTTING FORCES. The hammer is placed at the rear end of the spindle and supplies the motion and energy required for a cut. Polytechnic Institute, Turin, Italy

ball bearings for machine tools, Fiat also has an interest in Cimat, a manufacturer of grinding machines.

2.7.5. ITALIAN MACHINE TOOL RESEARCH IN GENERAL. Italian machine tool builders today often rely on license agreements with other companies to keep their equipment modern and competitive. The awareness of their lack of research activities resulted in the formation of the previously mentioned co-operative research centers in Turin and Milan. As pointed out by an Italian engineer, Italian history offers many examples of a competitor being eliminated by poisoning in days gone by. In spite of this tradition of deadly rivalry, many steps are being taken today to bring about co-operative development and research activities in the machine tool field.

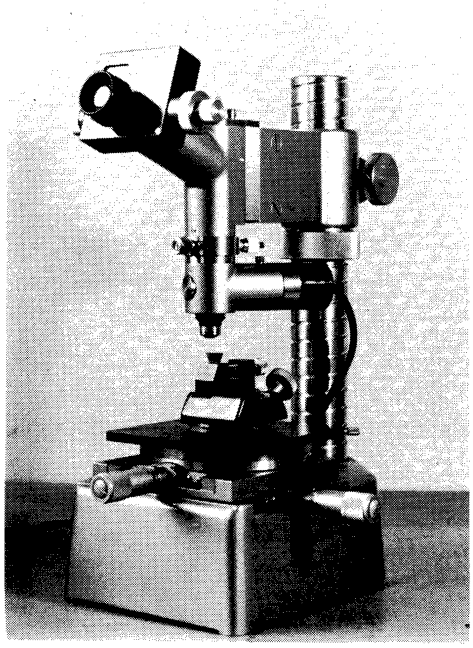

FIGURE 17. MICROSCOPIC TOOL WEAR MEASUREMENT FOR STATISTICAL ANALYSIS. Polytechnic Institute, Turin, Italy.

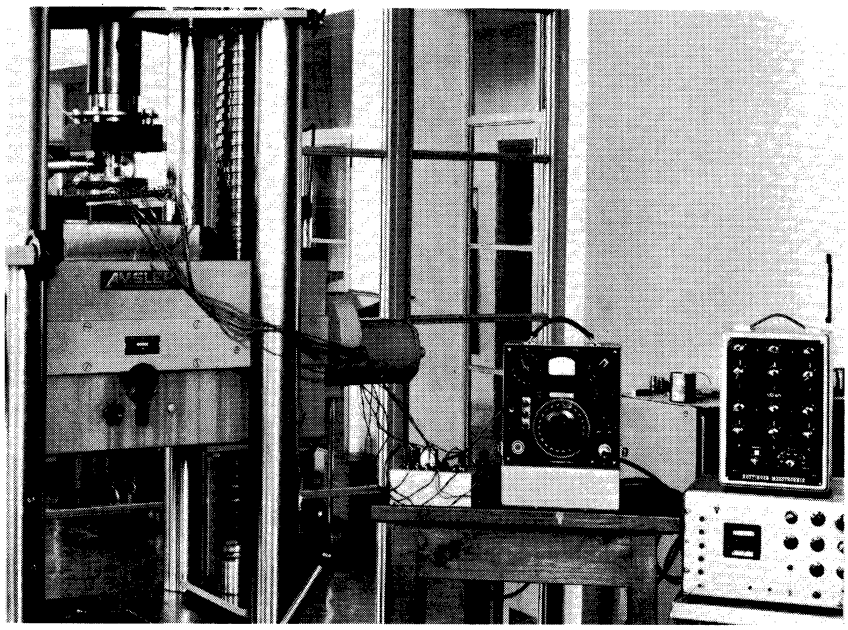

FIGURE 18. STRAIN MEASUREMENTS IN A STRESSED WORK PIECE HAVING A CONVEX PROFILE. Italian Measurements Institute, Turin, Italy.

A look into the shop of an Italian machine tool builder will show modern machine tools being produced on late model equipment. Many Italian production shops have machine tools of Italian, French, German, British, U.S., Swedish, Czech, USSR, and Hungarian make. Machine tools from Soviet countries come into Italy through barter deals for other Italian products. With very few exceptions, no dissatisfaction with various Soviet machine tools was expressed. The acquisition of Soviet machines was often based upon their being cheaper than Italian or other kinds of machine tools. Italian machine tool builders usually considered Western European and U.S. machine tool builders their main competitors, from whom they often obtain licenses for specific features which they incorporate in their own designs. One Italian machine tool company, employing over 500 people and exporting to all parts of the world, did little research, but paid over $200,000 a year in license fees to U.S. and Western European companies.

Appendix A
COMMENTS ON MACHINE TOOL RESEARCH IN SOVIET COUNTRIES

Because the machine tool industry is recognized in Eastern European countries as the key industry, it is only natural that machine tool research and design is mainly state directed.

The large machine tool research and development laboratories in Soviet Russia, like the experimental Scientific Research Institute for Metal Cutting Machine Tools (ENIMS) in Moscow, have a correspondingly large research and technical staff numbering 2000 to 4000 people. Although these figures include shop workers who build experimental and prototype machine tools, most of the employees are research engineers, designers and technicians. The standardized machine tool as prototyped by ENIMS is then built in a specialized factory. Although this factory may design machine tools, these also have to be approved by ENIMS, which controls all machine tool designs manufactured in the Soviet Union. This institute is divided into the three major sections of technology, metallurgy, and design, and incorporates 50 laboratories and divisions. Other large machine tool laboratories are established in various Soviet republics.

Visitors to machine tool laboratories in communist states have reported that a similar situation exists in all of them. Among these state-directed laboratories, the Research Institute for Machine Tools and Metal Cutting (VUOSO) in Prague is best known in the Western countries and can be considered the most advanced outside of Russia.

The VUOSO Research Institute is the central but independent research and development laboratory for the state-organized machine tool and tool industry, TOSAN, in Czechoslavakia.[3] This institute has two basic divisions, machine tool research and metal cutting research.

Other activities include technical information service, patents, and standardization. The institute has established test procedures for new prototype machine tools which are used for checking accuracy and static stiffness, as well as stability against self-excited vibrations. New tool designs are developed and tested as well as techniques for determining and measuring surface finish. Economic studies regarding new machine tools are also carried out. Graduates of technical universities are given research assignments in the machine tool field and their findings are incorporated in theses submitted as partial requirements for advanced university degrees.

[3] The VUOSO institute was founded about 12 years ago and is now incorporated as an independent unit in TOSAN, the Czech association of machine tool and tool manufacturers.

Professor Eisele, of the Technical University, Munich, noted in an examination of the Melman Report that the valuable research work done by these laboratories with their large staffs, well equipped buildings, and massive budgets includes not merely research work but also design and constructional projects which in the West would be carried out in the machine tool factories. Their generally very small design departments do not reach the Western average. Professor Eisele also noted that ENIMS designed and built the automatic production line for gears in the Moscow lathe plant, whereas in the West no research institute would be given such work, and he concluded that it would be very difficult to estimate the proportional division of an institute's activities between real research and other activity. It seems that the Soviet machine tool industry is concerned with a much smaller number of types than are the Western industries, and this concentration reflects a planned feature in a state-controlled industry which has long operated under its own minister.

Appendix B
EUROPEAN UNIVERSITIES AND INSTITUTES

There follows a list of Western European universities and institutes concerned with machine tool research. Those visited in 1962 are starred.

Austria

*Technical University Vienna (Professor Tschirf)
Technical University Graz (Professor Musyl)

Belgium

University Catholique de Louwain, Institute of Metal Processing (Professor Peters)
University of Brussels
University of Liège (Professor Bodart)
Technical Institute Mons (Professor Molle)

Great Britain

*Institute for Advanced Studies in Engineering Science, University of Birmingham (Professor Tobias)
*Northampton College of Advanced Technology, London (Messrs. Williams and Finkelstein)
Production Engineering Research Association (PERA) (Dr. Galloway)
Manchester College of Science and Technology (Professor Koenigsberger)
Edinburgh University
Glasgow University
Manchester University
University of Wales
Machine Tool Industry Research Association (MTIRA)
National Engineering Laboratory (NEL), East Kilbride
Department of Scientific and Industrial Research of the British Government
College of Advanced Technology, Salford (Professor Chisholm)
College of Aeronautics, Cranfield (Professor Loxham)

Denmark

* Machine Tool Research Institute, Technical University, Copenhagen (Professors Olsen and Jeppesen)

France

* Centre d'Etude et de Recherche de la Machine Outil (CERMO, Mr. Lombard)
* Laboratoire Central de l'Armement (Mr. Weill)
Ecole Polytechnique, Paris
SEMO (Section for Industrial Machines and Machine Tool Testing)
Ecole Central, Paris

Germany

* Institute Für Werkzeugmaschinen, T. H. Munich (Professor Eisele)
* Technische Hochschule, Braunschweig (Professor Pahlitzsch)
* Technische Hochschule, Hanover (Professor Osenberg)
* Technische Hochschule, Aachen (Professor Opitz)
* Technische Universität Berlin (Professor Schallbroch)
Technische Hochschule, Stuttgart (Professor Dolezaleck)
Technische Hochschule, Karlsruhe (Professor Schmidt)
Technische Hochschule, Darmstadt (Professor Stronberger)
Battelle Institut, Frankfurt

Holland

Technische Hogeschool, Delft (Professor Pekelhaering)
T. N. O. (Applied Scientific Research), Delft (Remmerswaal)

Italy

* Istituto Politecnico di Torino (Professor Micheletti)
* Istituto Dinametrico Italiano (Professor Bray)
Italian Association for Development of Research in the Machine Tool Field (SVIMU)
Association for the Development of Metal Cutting (ASVILMET)
University of Milano
University of Genoa
University of Trieste
University of Naples

Norway

University of Trondheim (Professor Andersen)

Sweden

Chalmers Technical University, Goteborg (Professor Svahn)
Technical University of Stockholm (Professor Hallendolf)

Switzerland

Eidg. Technische Hochschule, Zurich (Professor Bickel)
Battelle Institut, Geneva

Spain

* Escuela Superior de Ingenieros Industriales, Madrid (Professor Muñoz)
Escuela Superior de Ingenieros Industriales, Bilbao
Escuela Superior de Ingenieros Industriales, Barcelona
* Centro de Estudios Tecnicos de Automocion, Madrid (Mr. Ricart)

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Inst. of Science and Technology, U. of Mich., Ann Arbor
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(Memo no. 66223-11-R) Unclassified Memorandum

This report covers a three-month tour to investigate machine tool research activities in firms and institutes in seven Western European countries, including France, Spain, Italy, Germany, Denmark, Austria, and England. The information gathered was to be used for comparative purposes in the Industrial Development Research Program's survey of the Michigan machine tool industry. Visited were 25 firms and 15 institutes that conduct research in production and machine tool dynamics.

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DESCRIPTORS

Machine tool industry
Industrial research
Industrial equipment
Industrial plants

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