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MANUFACTURING METHODS RELATED TO THE
INTERNATIONAL PROGRAM OF COOPERATIVE
DEVELOPMENT IN METAL CUTTING

FIRST TECHNICAL REPORT
Covering the Period
1 June 1966 to 30 May 1967

Approved for Public Release; distribution is unlimited.

Prepared under Contract AF 33(615)-3835
by

M. Eugene Merchant
Director of Scientific Research
The Cincinnati Milling Machine Co.
Cincinnati, Ohio

MMP Project Nr. 9-712

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FOREWORD

This Technical Report describes the work done and accomplishments obtained in the cooperative international research program of the CIRP/OECD Group of Experts on Metal Cutting (Working Group C) during the period 1 June 1966 to 30 May 1967. It is prepared for internal use by MATF to assist in organizing and planning effective Air Force manufacturing development programs in the overall field of material removal processes. The information it contains was obtained by Dr. M. Eugene Merchant, Director of Scientific Research, The Cincinnati Milling Machine Co., Cincinnati, Ohio, through his personal attendance at the meetings of the CIRP/OECD Group held during that period and his personal participation in the activities of that Group as one of the official U. S. participants in its work.

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1. BACKGROUND INFORMATION

The objective of the program of cooperative international research work being carried on by the CIRP/OECD Group of Experts on Metal Cutting (Working Group C) is to conduct a scientific study of the relation of the machining characteristics of steel to its properties and metallurgical structure in order to provide a sound basis for predicting the machining performance of steels in manufacturing operations.

The current list of participants in this program (effective 25 January, 1967) is given in Appendix I. It may be noted that the list of participating countries now includes several Soviet bloc countries. This is due to the new status of the Group, under OECD aegis, granted to it by OECD on 25 January, 1967, as explained in Section 5 of this report.

2. NATURE OF THE MEETINGS HELD BY THE GROUP

2.1 Description, Locations and Dates

During the period 1 June, 1966, to 30 May, 1967, the Group hold the following meetings, attended by the writer:

Seminar on Metal Cutting
OECD Headquarters
Chateau de la Muette
Paris, France
1 and 2 September, 1966

Subgroup on Forces and
Mechanics of Cutting
OECD Offices
91 Boulevard Exelmans
Paris, France
24 January, 1967

Ninth Plenary Meeting
OECD Offices
91 Boulevard Exelmans
Paris, France
25 January, 1967

The work done and accomplishments obtained in the cooperative program were reviewed and reported at these meetings, and this report is therefore organized in terms of these two sets of meetings (September 1966 and January 1967).

2.2 Programs and Agenda

The program for the Seminar is reproduced in Appendix II and the agenda for the Subgroup meeting and the Plenary meeting are given in Appendices III and IV respectively.

2.3 Participation

The list of participants in the Seminar on Metal Cutting is given in Appendix V.

3. SEMINAR ON METAL CUTTING

3.1 General

The purpose of the Seminar on Metal Cutting was to review the results obtained by the CIRP/OECD Group of Experts on Metal Cutting in its program to date and to obtain critical comments from the audience to help to further improve the effectiveness of the program in its continuing activities. It was therefore primarily addressed to representatives of industry and scientists other than those cooperating in OECD research groups. However, in order to

obtain maximum interchange of information, attendance was limited to approximately 100 persons, including the members of the Group of Experts.

3.2 History, Tasks, and Achievements of the Group of Experts on Metal Cutting (Paper No. 1 by Mr. M. R. Weill, Chief Military Engineer, Central Armament Laboratory, Paris, France)

A variety of important factors at work in the world today make it very important that the nations cooperate in a program of metal cutting research. Among these factors is the rapid growth of numerical control with its requirement for accurate advance prediction of the machining characteristics of a great variety of work materials. Another factor is the advent of a variety of new types of alloys to be machined, including many of much higher strength than those encountered in the past, all posing significant machining problems. A further factor is the large role played by the machining process in the economy of most nations today, its use by industry constituting a sizeable percentage of the gross national product of each nation. Thus improvements in machining efficiency of even as little as 1% can have a significant impact on a nation's economy.

In the program of the Group of Experts to date the major accomplishment has been the establishment of an international basis for comparing machining results and obtaining comparable reproducible results in machining studies of such quantities as forces, surface finish, and tool life in various laboratories throughout the world.

The second phase of the program will begin the work of establishing the relationships between the metallurgical properties of different steels and their machinability, as well as providing fundamental information on tool wear and other performance factors, and integrating the machining data into programs for use in numerical control of machine tools.

It seems from the progress already made that cooperative research is probably the only way to achieve the coordination required by the challenge of modern technology of the work being done on metal cutting all over the world. Without such an approach, the work of individual laboratories has to remain too specialized and the broad problems challenging manufacturing today will not be solved.

3.3 Study of Machined Surfaces (Paper No. 2 by M. C. Shaw, Carnegie Institute of Technology, Pittsburgh, Pennsylvania, U.S.A.)

In the cooperative research program, the Subgroup on Surface Finish and Surface Quality studied the surface finish obtained when machining the OECD XC45 steel over a wide range of cutting conditions. They found that there are several critical speeds associated with the finish produced by the primary cutting edge of a turning tool. This is due to the fact that the built-up edge on the face of the tool disappears when the tool face reaches a certain critical temperature (associated with a certain critical cutting speed), thus eliminating roughness due to fragments of built-up edge. However, surface finish continues to improve with increase of cutting speed beyond this first

critical value and does not reach its optimum until the temperature on the clearance face of the tool reaches the same value as that which existed on the tool face at the speed (temperature) at which the built-up edge disappeared. The work surface then has a burnished appearance.

The cutting speed at which the built-up edge disappears was found to correspond to the speed at which the cutting force reaches a maximum value and also at which the face of the chip first has a burnished appearance.

3.4 Mechanics of Cutting and Cutting Forces (Paper No. 3 by Mr. M. F. Eugene, Chief Military Engineer, Central Armament Laboratory, Paris, France)

The work on the Subgroup on Mechanics of Cutting and Cutting Forces has concentrated largely on developing methods for obtaining comparable reproducible metal cutting force measurements between different laboratories. The test methods for making force measurements were standardized and comparisons then made between the force dynamometers used in the seven cooperating laboratories. After comparing the results, it became evident that a standard dynamometer should be designed and constructed for use in the later phases of this program and a cooperative program to do this was instituted.

3.5 Behavior of High Speed Steel Tools (Paper No. 4 by Prof. E. Bodart, Institute of Mechanics, University of Liege, Liege, Belgium)

A great variety of comparative tool life tests with high speed steel tools were run on the XC 45 steel by the different laboratories participating in the program of the Subgroup on Behavior

of High Speed Steel Tools. They found that it was much more difficult to obtain comparable and reproducible results between laboratories in tests with high speed steel tools than in tests with carbide tools. This is largely due to the fact that with high speed steel tools a built-up edge is present. It was found, however, that more reproducible results could be obtained with an 18-4-1 type of high speed steel containing 10% cobalt than with a 10.5 W-3.5 Mo-4.5 Cr-3 V high speed steel containing 10% cobalt. This led to the conclusion that it is desirable for reproducible tool life testing to use types of high speed steel which are least sensitive to small differences in heat treating procedure. Further, it was found that more reproducible results can be obtained with one piece tools than with brazed tip tools. The work of the Subgroup also confirmed the fact that with high speed steel tools the cutting speed for a 60 minute tool life can be very considerably increased by using rake angles of the order of 25° to 35° instead of the usual 15° .

3.6 Behavior of Carbide Tools (Paper No. 5 by Professor H. Opitz, Director of the Laboratories for Machine Tools and Manufacturing Technology, Technical University, Aachen, Germany)

The Subgroup on Behavior of Carbide Tools running tool life tests on the XC 45 steel found that it could obtain quite reproducible results with carbide tools. As a result, a number of types of studies were run to relate tool wear to various other characteristic factors in the metal cutting process and to the characteristics of the steel.

Concerning the relation of tool wear to the other characteristic factors in the metal cutting process as a function of cutting speed, it was found that the behavior of the built-up edge as a function of cutting speed ties these together. The relationships found are shown in Figure 1. For the conditions shown here, separate tests had revealed that the built-up edge, which was small at quite low speeds, gradually increased in size up to a speed of about 10 meters per minute where it reached a maximum. Beyond this speed, the built-up edge began to decrease in size until at about 30 meters per minute it disappeared. As can be seen, in the range of increasing size of built-up edge with increasing speed, flank wear decreases and reaches a minimum when the built-up edge is maximum, tangential cutting force decreases and reaches a minimum when the built-up edge is maximum, surface roughness increases and reaches a maximum when the built-up edge is maximum, and cutting temperatures remain quite low. In the range where the size of the built-up edge decreases with increasing cutting speed flank wear first increases then decreases to a minimum at the point where the built-up edge disappears, cutting forces increase and reach a maximum at the point where the built up edge disappears, surface roughness decreases and reaches a minimum at the point where the built-up edge disappears, and cutting temperature rises rapidly with increasing speed until the point where the built-up edge disappears. Beyond the point where the built-up edge has disappeared, the various characteristic factors

behave in their usual normal way with increasing speed, namely, tool wear increases rapidly with increasing speed, forces fall with increasing speed, surface finish remains virtually unaffected by increasing speed, and cutting temperature rises steadily as the speed is increased.

Concerning the relationship of tool wear to the characteristics of the steel, the Subgroup ran tests with two steels of the same type but from two different melts. The first was a vacuum melt to eliminate all oxide inclusions. The second was a melt in which the steel was deoxidized in such a way as to produce oxide inclusions of a type which would build up a protective film on the face and flank of the tool during machining. In preliminary tests on these steels using carbide tools containing titanium carbide all the members of the Subgroup found considerably less tool wear when machining the specially deoxidized steel than when machining the vacuum melted steel. The program of study on these two steels was still in progress at the time the Seminar was held.

3.7 Steel Preparation (Paper No. 6 by Mr. J. Pomey, Honorary Scientific Director, Renault Corporation, Paris, France)

For the first phase of the Cooperative Research Program (that aimed at obtaining comparative reproducible results between laboratories) this Subgroup arranged for and secured a uniform homogeneous XC 45 (0.45 C) steel made to the following requirements:

- a. Chemical homogeneity and purity of the liquid steel obtained by the electric steel making process with induction stirring.

- b. Homogeneity during solidification without any segregation obtained by the continuous casting technique.
- c. Accurate and uniform heat treatment of the bar stock by means of a continuous process using special equipment to obtain the required structure and hardness values.

For the second phase of the Cooperative Program (that aimed at relating machining performance to the structure of the steel) the Subgroup has arranged for a chromium-nickel and chromium-molybdenum steel to be made to the same requirements as those indicated above in the following structures:

- a. ferrite and lamellar pearlite obtained by isothermal transformation during annealing
- b. ferrite and globular pearlite, softer than the above, obtained by additional annealing at just below the A_1 critical temperature
- c. sorbite structures obtained by martensitic quenching followed by tempering at various temperatures corresponding to ultimate tensile strengths of 107, 95, and 83 kilograms per square millimeter
- d. globular cementite on a ferrite matrix a little softer than the last-named structures, obtained by further annealing of the steel (hardened and tempered as above) at a temperature just below the A_1 point.

3.8 Plasticity in Cutting (Paper No. 7 by Professor O. Svahn, Head of Division Production Engineering, Chalmers Technical University, Gothenburg, Sweden)

The Subgroup on Plasticity in Cutting has studied the plastic properties of the XC 45 steel in relation to the cutting performance data obtained by the other Subgroups. From the results obtained, it was found that the plastic behavior under cutting conditions (high strain rates, high temperatures, extreme contact conditions, and high plastic strains) for the XC 45 material correlates very favorably with tensile stress-strain data and other measurements of plastic properties made under normal test conditions. Thus plastic deformation studies show some promise of being a useful bridge between test data obtained on the material and machinability data to be used in production.

3.9 Cutting Temperatures (Paper No. 8 by Dr. M. Pesante, Central Experimental Laboratory for Metals, Torino, Italy)

The Subgroup on Cutting Temperatures has studied various methods of measuring cutting temperature to evaluate their suitability for use in obtaining reproducible and meaningful data in the Cooperative Research Program on Metal Cutting. The various methods studied and the conclusions reached to date on these are as follows:

- a. Built-in thermocouple method by Kuester. This method uses a thermocouple imbedded in the tool and attempts to extrapolate the observed temperature within the tool to that at the chip-tool interface. It has been found possible by this method to study the temperature

distribution on the surface of the tool in relation to cutting speeds and feeds by varying the position of the thermocouple and analyzing the resulting data with a special computer program. The method shows promising results which are well in agreement with those obtained in other research as well as those obtained by calculation. This method and the emitted radiation method have the advantage that they can also be used to determine the temperature distribution on the flank of the tool.

- b. Emitted radiation method. This method is based on measurement of the infrared radiation emitted by the chip flowing over the tool face through a tiny hole drilled in the tool or through a tiny hole drilled in the workpiece. The method, therefore, comes close to being an absolute method useful for reference purposes when other temperature measurement methods are under study. In this study so far, this method has given very consistent and repeatable results.
- c. Tool-workpiece thermocouple method (Gottwein). In this method the cutting tool is taken to be one element of a thermocouple and a workpiece the other. One of its drawbacks is that the measured temperature value is only a general indication of the average temperature

existing on the combined face and flank of the tool. Another drawback is the difficulty of calibration of the thermo-electric system. Nevertheless, this method is the simplest to use in practice and, therefore, has been widely employed in the past. However, so far it has always given cutting temperatures that are low compared with those obtained by other methods.

- d. Twin-tool thermocouple method. This method makes use of the thermo-electric potential developed at the contact zone of two lathe tools of different chemical composition which are simultaneously machining the same material. It has the advantage that the apparatus needs to be calibrated only once no matter what material is to be machined. However a disadvantage of the system is that the temperatures in the zones of contact between the two tools and the workpiece may be different, with the result that the temperature reading on the apparatus is something of a mean value between the two mean temperatures for the two tool-workpiece contact zones. Another drawback is that the cutting speed is limited by the cutting ability of the least capable of the two tools.

In spite of these disadvantages, at least one large manufacturer in Italy is using this method to rate the machinability of batches of steel as received before they are

released to the manufacturing departments.

The Subgroup will continue its study of various methods of measuring cutting temperature with the hope of developing short time tests which could be used to determine the machinability of steels and find optimum cutting conditions in practice.

3.10 Statistical Programming (Paper No. 9 by Professor H. Opitz Director of the Laboratories for Machine Tools and Manufacturing Technology, Technical University, Aachen, Germany)

The Subgroup on Statistical Analysis of Data carried out tests to determine the uniformity of the carbide tool tips used in the Cooperative Program. In addition, it statistically analyzed the results of the tool life tests.

Concerning the study of the uniformity of the carbide tool tips, it was found that the standard deviation of the Rockwell A hardness for the entire set of tool tips used in the Cooperative Program was only about ± 0.1 . This was considered very good since this standard deviation is of about the same order as the accuracy of reading the hardness measuring instrument.

Concerning the tool life tests made with carbide tools, a regression analysis of the data from the different laboratories resulted in equations for flank wear for the machining of the XC 45 steel as follows:

$$\begin{aligned} \text{For grade P 10 carbide: } v^{1.23} \cdot T^{0.56} &= 290 \text{ VB} \\ \text{For grade P 30 carbide: } v^{2.0} \cdot T^{0.8} &= 9850 \text{ VB} \end{aligned}$$

Where

v = cutting speed (meters per minute)
 T = cutting time (minutes)
 VB = flank wear (millimeters)

Tests to evaluate the influence of the side cutting edge angle on flank wear were also subjected to regression analysis resulting in the following equation:

$$VB = 0.3 \times 10^3 v^{1.6} \cdot T^{0.6} \cdot (sx)^{0.5}$$

Where

s = feed rate (mm/rev)
x = 90- side cutting edge angle
VB = flank wear (mm x 10⁻²)

and the other quantities are as above. It can be seen from this equation that feed rate could be doubled if the side cutting edge angle is increased from 0° to 45° without any decrease in tool life. This is a result which is understood to a certain extent qualitatively in practice, but the large quantitative benefits available here are seldom taken advantage of.

3.11 Unification of Measuring Methods (Paper No. 10 by Mr. M. R. Weill, Chief Military Engineer, Central Armament Laboratory, Paris, France)

The Subgroup on Standardization of Tests developed standard terminology, procedures for the measurement of tool wear, and definitions of tool angles for use in carrying out the research of the Cooperative Program. The procedures adopted for the measurement of tool wear are shown in Figure 2 and the adopted definitions of tool angles in Figure 3.

The Subgroup was asked by ISO to prepare a draft standard on the method of tool life testing for consideration by

ISO TC 29 for adoption as an ISO standard and is preparing such a document. This document will allow the test conditions, tools, work material and cutting fluids used in all laboratories and shops throughout the world in making cutting tests to be standardized. Results of such tests could then be exchanged, avoiding duplication, and direct comparisons between results obtained in one laboratory or plant and another should be possible.

3.12 Modern Manufacturing Trends, Needs, and Optimization Technology and Their Implications for Metal Cutting Research
(Paper No. 11 by Dr. M. E. Merchant, Director of Scientific Research, The Cincinnati Milling Machine Company, Cincinnati, Ohio, U.S.A.)

Important economic and technical factors at work today pose a growing need for rapid development and application of optimization technology for metal-cutting manufacturing. The major economic factor is the fact that machining costs in industrially-developed countries now amount to something of the order of 5% of the gross national product. The major technical factors are the requirements for greater product variety, closer tolerances, increasing variety and strength of work materials, greater emphasis on conserving materials, and an increasing necessity for improved communication and feedback between the manufacturing process and the design process. These economic and technical challenges are resulting in the rapid development and application of a number of new optimization techniques. Among the most important of these are the systems approach to manufacturing, the application of computers to manufacturing, design for production,

part-family manufacturing (group technology), numerical control and adaptive control. These factors and developments necessitate that research on machining be strongly oriented toward optimization of the metal-cutting manufacturing process. Specifically, these considerations suggest that in the work to be done in the second phase of the program of cooperative international research of the Group of Experts on Metal Cutting, careful consideration be given to the trends, needs and optimization technology referred to above, and the research work be so oriented as to contribute most effectively to optimization of metal-cutting manufacturing relative to these factors. Further, it is concluded that there is an important economic and technical need to originate a cooperative international research program on optimization technology in manufacturing.

3.13 Additional Contributions

3.13.1 Wear of Finish Turning Tools (Contribution No. 1 by Professor A. J. Pekelharing and C. A. van Luttervelt, Technological University, Delft, The Netherlands)

In connection with their participation in the activities of the Subgroup on Surface Finish and Surface Quality, these two researchers have studied the formation of small grooves on the end cutting edge of a tool and the influence of this type of tool wear on workpiece roughness and diameter. A cutting tool will show wear marks after cutting for some time. Figure 4 shows schematically what happens to the tool and the surface roughness

as a function of cutting time. Examination of the tool through a microscope reveals small grooves in the end cutting edge, the distance between one groove and the next being equal to the feed distance. Workpiece roughness then no longer depends on the original nose radius of the tool but on the shape of the grooves. The roughness increases rapidly during the first few minutes of cutting while the first groove is being formed (soon to be followed by the second and third groove). The value of the roughness depends then on the depth of the grooves. After some time the rapid increase in groove depth comes to an end; this depth becomes more or less stable and so does the roughness. The reason for the formation of the grooves seems to be that at the point where they form the tool is cutting metal which has been previously cut and is thus heavily work-hardened. Another effect of this grooving wear of the end cutting edge is that workpiece diameter will increase rapidly along with roughness. Thus the end point of tool life may be reached rapidly due to excessive roughness or due to excessive diameter change.

3.13.2 On the Basic Mechanisms of Metal Cutting (Contribution No. 2 by Mr. J. Pomey, Honorary Scientific Director, Renault Corporation, Paris, France)

In connection with the work of the Subgroup on Mechanics of Cutting and Cutting Forces, Mr. Pomey proposes that research be done to obtain a better understanding of the fundamental mechanisms in metal cutting by independently studying the two main

mechanisms of that process, namely, plastic flow of the metal as it occurs in the shear zone and sliding friction as it occurs between the chip and tool. He proposes that a considerably improved knowledge of the fundamental mechanisms in metal cutting could be obtained by studying adiabatic plastic flow of metals under conditions where the stresses, strains, and strain rates are comparable to those obtained in metal cutting and by experimental investigation of the dry friction between clean surfaces under conditions similar to those existing between the chip and tool in metal cutting. He suggests further that these two fundamental mechanisms of metal cutting might even be studied separately in the metal cutting process by using various means such as transverse vibratory motion and lubrication to reduce the friction between chip and tool to very low values.

3.13.3 Oxidation of Carbide Cutting Tools Often Determines Tool Life (Contribution No. 3 by Professor A. J. Pekelharing and C. A. van Luttervelt, Technological University, Delft, The Netherlands)

In connection with their work on the Subgroup on Behavior of Carbide Tools, these authors have made an important discovery concerning the mechanism of failure of carbide tools in practice. They have found that in the majority of cases the cutting edge of a carbide tool crumbles away and fails not because of crater wear per se but rather because of oxidation of the end cutting edge of the tool occurring at the point where the inactive end cutting edge meets the active end cutting edge. Here oxidation of the carbide goes on

continuously and rapidly, generating a pit that gradually erodes its way into the crater, thus eating away a part of the rake face. This reduces the support given to the chip and increases the pressure on the tool nose. After some time the nose can no longer carry this heavy load and becomes deformed and collapses.

Their studies showed that the presence of titanium carbide in the tool material makes tools less prone to oxidation, accounting for the better tool life obtained with TiC tool materials.

3.13.4 Application of Statistical Techniques to Machining Experiments (Contribution No. 4 by Mr. G. Lorenz, National Standards Laboratory, Division of Applied Physics, Sydney, Australia)

In connection with the activities of the Subgroup on Statistical Analysis of Data, Mr. Lorenz points out that the use of statistical design of the experiments to be carried out in Phase II of the Cooperative Research Program could considerably increase the reliability of the results obtained as well as reducing the number of tests required in the program. His recommendations were taken under consideration by the group.

3.13.5 Remarks on Plastic Chip Formation (Contribution No. 5 by Mr. J. Pomey, Honorary Scientific Director, Renault Corporation, Paris, France)

In connection with the work of the Subgroup on Plasticity in Cutting, Mr. Pomey points out that one of the chip photomicrographs obtained in the studies made by that group seems to clearly demonstrate that the instability associated with adiabatic plastic deformation is present in the chip formation process. He suggests that an independent adiabatic torsion test be run on

the same metal with the same values of stress, strain, and strain rate as occurred in the metal cutting tests to determine whether the results do indeed correlate. Thus this proposal is an extension of that made by Mr. Pomey in Contribution 2.

3.14 Discussion and Recommendations

Following the presentation of the papers and additional contributions of the Seminar, the floor was opened to discussion and recommendations from the different national delegations. A summary of the more pertinent of these follows.

Mr. M. F. Jamar of F.N.A.G. of Belgium stated that he agreed with the emphasis which the Group of Experts is putting on economic aspects and optimization in its Program of Cooperative Research. He then cited some results from some tool life studies which his company has been making in their shops on operations done with complicated high speed steel form cutters and using surface finish as the criterion for the end point of tool life. They studied the effect of rake angle and found that a 27° rake angle is optimum. This angle, they found, corresponds to the natural angle generated on the face of the cutting tool by the formation of a crater. With the 27° rake angle, not only was tool life a maximum, but also the built-up edge was virtually eliminated. On some other studies with carbide tools they found that grinding an artificial crater on the tool face having a rake angle of 25° to 30° they were able to increase cutting speed from 90 meters per minute to 400 meters per minute with an actual increase in tool life

at the same time.

Mr. Champetier of the French Ministry of Research read a prepared statement from the French Machine Tool Builders' Association that the Association urged the Group of Experts to bear in mind that the machine tool and the cutting tool together form a system and that, therefore, in their studies on the metal cutting process and the wear of cutting tools, they should not overlook the influence of the machine tool on the results obtained. They pointed out further that the rapid development of numerical control and adaptive control of machine tools required an expanded knowledge of the fundamentals of the metal cutting process, but went on to say that they could now foresee, by virtue of the work being done in this Cooperative International Research Program, a harmonization of metal cutting research with the needs being generated by these new methods of machine tool control. They, therefore, offered their congratulations to the Group on responding to this need.

Mr. Siebel of the Krupp Company in Germany stated that he also agreed that optimization of machining is one of the most pressing needs today. In his opinion, this can only be done by cooperative international research carried on among the different nations in the manner now being done by the Group of Experts. The problem is so large that no one laboratory, and even no one country, could carry out research commensurate with the need. Mr. Siebel recommended to the Group that in their future program they include more work on the

factors affecting surface finish and that they also investigate other machining processes such as drilling, milling, etc., in addition to turning.

Dr. Lippman of the Applied Mechanics Institute of the Technical University of Braunschweig, Germany, recommended to the group that they expand their research on plasticity effects in metal cutting. He indicated that he believes there is need for more than the simple model of the metal cutting process which exists today, that there is a need for an improved mathematical model of metal cutting, and that there is a need for better methods of measuring metal flow in chip formation. He also indicated that he believes there is a need to know more about the causes of vibration arising from the metal cutting process itself, as well as a need to know more about the causes and control of residual stresses produced by the metal cutting process.

Mr. Sten of the Swedish Association of Metalworking Manufacturers congratulated the Group of Experts on the fine Program of Cooperative Research which they have underway to meet the challenge of today's rapidly advancing manufacturing technology. He then went on to indicate that Swedish metalworking manufacturers have also been responsive to this challenge and have established a Swedish Institute for Production Engineering Research to carry out research programs for Swedish industry on a cooperative basis.

Mr. Barlow of the Shell Corporation in Great Britain recommended that the Group of Experts in its continuing program give greater emphasis to the effect of the environment (i.e., cutting fluids atmospheres, etc.) on the performance of the metal cutting process.

Dr. E. M. Trent of Hard Metal Tools Ltd. of England stated that he felt that the work of the Group represented a considerable advance over past activities in the field of metal cutting research. The Group has not buried itself in studying only the mechanics of cutting and the equations associated with this, but instead has challenged the existing knowledge and gone on from there. He recommended that in the future program, the Group study the flow of metal on the tool face and the cutting edge more thoroughly since this is not a conventional sliding or friction process. He also recommended that the Group study a variety of worn tools (both finishing and roughing) taken from a variety of operations in industrial plants to determine what caused the end point of tool life in each of these actual operations; flank wear and crater wear alone are too simple as criteria for the end point of tool life. He also recommended more study on actual tool properties in relation to performance; more needs to be known about the fracture of tools and about test methods to determine toughness. He also recommended that study of the machining properties of cast iron and of difficult to machine materials be included in the program. Finally he recommended

pursuing further the studies on non-metallic inclusions and on grooving wear.

Dr. McPherson of Illinois Institute of Technology, U.S.A., recommended that the Group of Experts in its continuing program actively pursue the objective of relating machining performance to the metallurgical structure of the work material and of the cutting tool as well. He felt that particular emphasis should be given to developing information that would result in improved cutting tool materials.

4. RESULTS OF WORK OF PLENARY GROUP AND SUBGROUPS

4.1 General

During the period from the end of the Seminar to 30 May, 1967, work has been carried forward to plan the program for Phase II of the Cooperative Research and to begin initial research activities in this Phase. Based on the recommendations made at the Seminar, the Plenary Group has developed plans for extension and some re-orientation of its general program of research. In particular, plans have been developed for extending the work on developing a common language between the laboratories and for extending the fundamental research to be done in the program.

Concerning the development of the common language, the work to be done will include:

- a. Extension of standardized terminology to other machining processes, such as milling and grinding, and to cutting fluids.

- b. Extension of the standardization of test methods to such items as quick-stop mechanisms for studying chip formation, etc.
- c. Development of international ratings for metal cutting performance and machinability on such things as tool life, influence of metallurgical structures, cutting fluids, etc.
- d. Increase utilization of statistical methods in planning the test programs and evaluating the results.
- e. Development of a hand book on machining to include both a summary of the present state of the fundamental knowledge of metal cutting, and a summary of the results obtained from the Cooperative Research Program.
- f. Establishment of a systematic exchange of the results of machining research being pursued in different laboratories, whether or not these are being obtained as a part of the Cooperative Program.

Concerning the extension of the fundamental research on the phenomena of tool wear, such studies will be included as investigation of the behavior of the built-up edge over a wide range of feeds and speeds, investigation of metallurgical transformations taking place at the chip-tool interface, peculiarities in the trends of data such as that on cutting temperature, etc.

The work accomplished by each of the Subgroups in this period is summarized in the following Sections.

4.2 Subgroup on Mechanics of Cutting and Cutting Forces

The Subgroup has adopted a program of tests to be run on the chromium-molybdenum and nickel-chromium steels (in the six different structures of each). This will consist of measurement of cutting forces and cutting ratio over a range of feeds and speeds as in the Phase I study on XC 45 steel. In addition, however, temperature and surface finish will be measured during the tests. The temperature measurements will be made by whatever method each individual laboratory prefers and the results will be plotted for comparison of the trends of temperature with increasing speed and feed. The group will also prepare quick-stop chip specimens for the range of feeds and speeds studied in order to correlate the behavior of the built-up edge with the other quantities measured and observed in the program. For this work the various members of the Subgroup submitted descriptions of the apparatus and methods used in their own laboratories presently for making quick-stop tests. A specially appointed Task Force is studying these reports and will select from them a standard method to be used by all the cooperating laboratories.

Some of the members will also make measurements of the effective bearing area between the chip and tool (i.e., the percentage of the total area of the inside surface of the chip which actually comes in contact with the tool face when fragments of built-up edge are present).

Concerning the development of the standard dynamometer, two types of dynamometers able to meet the specifications set down by the Subgroup

have been built and are being tested at Professor Opitz's Institute in Aachen. One of these uses piezo-quartz sensors to provide high rigidity and therefore a very high natural frequency. However, it has been found very difficult to insulate these sensors in such a way that no leakage of charge occurs over the long periods of time involved in making a cutting test. In addition, interaction between the force components (i.e., application of force in the direction of the X component, for example, produces a reading on the Y and Z sensors) has been found very difficult to eliminate. The second type of dynamometer employs high sensitivity bonded strain gauges but is still able to maintain a minimum natural frequency of 1,700 cycles per second. Although this is not quite as high as hoped for in the specifications, nevertheless, the dynamometer meets all of the other specifications including extremely small interaction between the force components and, therefore, may prove to be the one best suited to be used as a standard by all participants. A Task Force is following the work on the two dynamometers and when the development of each is complete will make the selection of the one to be used as the standard dynamometer.

4.3 Subgroup on Surface Finish and Surface Quality

This Subgroup reported on studies made on the surface finish behavior of the two special XC 45 (AISI 1045) steels used in the investigation of the effect of a special deoxidation process for the steel on tool wear. The nature of these two steels is described in more

detail in Section 4.4 which follows. However, one is a vacuum deoxidized XC 45 steel and the other is an XC 45 steel deoxidized by a special method developed in Professor Opitz's laboratory at the Technical University in Aachen, Germany, and found to give a considerable reduction in tool wear when machined with carbide tools (especially those high in titanium content). The specially deoxidized steel is known to form a protective oxide layer on the face and flank of the titanium-containing carbide tools during machining.

The Subgroup particularly studied the effect which the special deoxidation treatment has on the cutting speed at which the built-up edge first disappears and on the cutting speed at which a fully burnished surface is first produced on the workpiece. It was found that the vacuum deoxidized steel and the specially deoxidized steel showed no significant difference in the cutting speed at which the built-up edge disappeared (about 48 meters per minute at a feed of 0.25 mm per revolution). However, this specially deoxidized steel gave a smaller built-up edge than the vacuum deoxidized. Concerning the cutting speed at which the finished surface just becomes burnished, however, it was found that the specially deoxidized steel gave a much lower value for this (155 meters per minute) than that obtained with the vacuum deoxidized steel (200 meters per minute). Thus the special deoxidation treatment not only reduces tool wear (see Section 4.4 which follows), but also gives an improvement in surface finish (due to the smaller built-up edge) and, at the same time, makes it

possible to obtain a burnished finish on the workpiece at a considerably lower cutting speed than is possible with the usual XC 45 steel.

4.4 Subgroup on Behavior of Carbide Tools

The major program carried out by this Subgroup during this period was a comparative test of the tool wear obtained when machining two different treatments of XC 45 steel (AISI 1045 steel) with carbide cutting tools. One of these steels was vacuum melted and the other was deoxidized by a special treatment developed at Professor Opitz's laboratory at the Technical University in Aachen, Germany. This treatment involves deoxidizing with an alloy of calcium and silicon, resulting in oxide inclusions in the steel which tend to form a protective layer on the face and flank of the carbide tool during machining.

The chemical composition of the two steels is as follows:

<u>Steel</u>	C	Si	Mn	P	S	N	Al	Cr	Cu	O ₂
SD	0.46	0.35	0.72	0.030	0.038	0.006	0.005	0.06	0.16	0.007
VM	0.46	0.22	0.56	0.032	0.026	0.005	0.005	0.07	0.17	0.002

(SD = Specially deoxidized . VM = Vacuum melted)

The Brinell hardness of the specially deoxidized steel was 186, and of the vacuum melted steel 190. The steels were machined with two different grades of carbide tools, designated P 10 and P 30. The composition of these tools is as follows:

<u>Grade</u>	<u>Source</u>	WC	TiC	TaC	CbC	Co
P 10	Soederfors	71	12		12.5	4.5
P 30	Widia	82		8		10

Tool wear tests were run on these steels by five participating laboratories, namely, Trondheim (Technical University, Trondheim, Norway), Cincinnati (Metcut Research Associates for the Cincinnati Milling Machine Company), Aachen (Technical University, Aachen, Germany), Delft (Technical University, Delft, The Netherlands), and Paris (Central Armament Laboratory, Paris, France). The tests were run over a range of cutting speeds from 80 to 200 meters per minute and over a range of feeds from 0.1 to 0.4 mm per revolution. Both flank wear and crater wear were measured and all of the laboratories agreed very well in the results obtained. Typical crater wear and flank wear results are shown in Figures 5 and 6 respectively (carbide P 10, cutting speed 200 meters per minute, feed 0.25 mm per revolution). It can be seen that flank wear when machining the specially deoxidized steel is only about 50% of that obtained when machining the vacuum melted steel. The crater wear results are even more striking since with the vacuum melted steel the crater depth increases with time in the usual manner whereas with the specially deoxidized steel not only does no crater form, but a protective layer actually builds up on the tool face increasing in thickness with time. Similar results were obtained over the whole range of speeds and feeds with the P 10 carbide tools. With the P 30 carbide tools (which do not

contain titanium carbide) similar results were obtained (flank wear reduced by half, crater wear eliminated by the special deoxidization treatment) up to a cutting speed of 125 meters per minute. Above this speed, however, crater wear began to occur with the P 30 carbide machining the specially deoxidized steel, although the flank wear values still remained half of those obtained with the vacuum melted steel over the whole range of feeds and speeds.

It is evident that this special deoxidation treatment provides a remarkable improvement in the machinability of carbon steels. Because of these results, the entire German steel industry has now converted its melting practices so that all carbon steels which it produces are deoxidized by this special process, resulting in a great improvement in the machinability of German produced carbon steels.

In order to plan the program of tool life tests to be run on the new chromium-molybdenum and chromium-nickel steels (in six different structures each) some preliminary cutting tests were run on samples of each of these twelve steels. It was found that these steels are very machinable so that a considerable amount of material will be required for each tool life test. Further, it was found that the differences in machinability between the six structures, for each of the two steels, are very small, indeed. In the light of this information a Program of Cooperative Tool Life Tests has now been drawn up for sharing the test work among the various participating laboratories and the testing is underway. Both P 10 and P 30 tool

materials will be used and the cutting speeds will cover a range from 60 to 250 meters per minute, while the feeds will cover a range from 0.125 to 0.5 mm per revolution. It was found necessary to use chip breakers for all tests (except where the effect of the chip breaker is being evaluated) because of the excellent chip formation properties of the test steels.

4.5 Subgroup on Behavior of High Speed Steel Tools

This Subgroup has made preliminary plans for a program of tool life tests to be run on the chromium-molybdenum and nickel-chromium steels (in six different structures each) to be divided among 13 different participating laboratories. However, before this is finalized, some preliminary cutting tests are being run to determine the best cutting conditions for these new steels in their different structures. It is expected that these cutting tests will be run using the new standardized 18-4-1 high speed steel throwaway tips now available from Sweden (see Section 4.10).

4.6 Subgroup on Plasticity in Cutting

This Subgroup has completed a program of preparing a series of quick stop chips from the original XC 45 (AISI 1045) steel and preparing a series of photomicrographs of the resulting chips. It is now proceeding to prepare a program for similar studies on the new chromium-molybdenum and nickel-chromium steels.

4.7 Subgroup on Cutting Temperatures

This Subgroup is continuing its study and evaluation of various methods for determining the temperature and temperature distribution

in the cutting zone in the manner described in the Paper given by Mr. Pesante at the Seminar on Metal Cutting (see Section 3.9). No new results have been reported since the Seminar on Metal Cutting.

4.8 Subgroup on Metallurgical Properties of Machined Steels.

This Subgroup completed its work of preparing and checking out the properties of the new batches of steels to be used in Phase II of the Cooperative Program. Shipment of these steels to 17 participating laboratories has now been completed. In all, approximately 80 tons of steel were prepared, checked, and shipped.

The chemical composition of the two steels is as follows:

	<u>Cr-Mo Steel</u>	<u>Ni-Cr Steel</u>
C	0.39	0.40
Mn	0.81	0.81
Si	0.29	0.41
Cr	1.28	1.06
Ni	0.27	1.48
Mo	0.31	-
S	-	0.009
P	-	0.010

The six structures in which each of the two steels were supplied are as follows:

- (1) ferrite and lamellar pearlite obtained by isothermal transformation during annealing;
- (2) ferrite and globular pearlite softer than the above, obtained by additional annealing at just below the A_1 critical temperature;

(3-5) sorbite structures, obtained by martensitic quenching followed by tempering at various temperatures corresponding to ultimate tensile strengths of 107, 95 and 83 hbar; and

(6) globular cementite on a ferrite matrix a little softer than the last-named structures, obtained by further annealing of the steel (hardened and tempered as above) at a temperature just below the A_1 point.

4.9 Subgroup on Statistical Analysis of Data

This Subgroup carried out two projects recently. The first was to analyze the causes of the high variability found in the tool life tests with high speed steel tools. When completed the statistical analysis showed that the observed variability in tool life in these tests was not due to the tool material nor the heat treatment. It was found instead that the variability was due mainly to effects introduced during the sharpening of the tools and to differences in the heat treatment of the individual tools arising from differences in the positions of the tool bits in the salt bath during heat treatment.

The second project involved the statistical planning of the tool life tests to be made with the carbide and high speed steel tools on the new steels. This resulted in a plan for selection of speeds, feeds, and the times at which wear measurements are taken that will provide a built in correlation between the experiments done in all

the different laboratories so that the results will be compatible. This plan has been adopted in the tool life tests being run with the carbide tools.

4.10 Subgroup on Standardization of Tests

At the request of the International Standards Organization (ISO) Technical Committee 29, this Subgroup undertook a project to develop a draft proposal for an ISO recommendation on tool life cutting tests with single point tools. This was done and the draft proposal has now been submitted to the ISO TC 29 secretariat which has put it in the hands of all members of that Committee asking for them to vote on whether an international standard on this subject should be established. The proposed standard has as its objective the providing of standard conditions and procedures for conducting cutting tests with single point tools so that:

- a. Results obtained in all laboratories can be compared directly.
- b. Scatter of the test results will be kept to a minimum.

It therefore spells out a standard work material, standard cutting tool materials, standard tool geometries, standard cutting fluids, standard cutting conditions, and standard criteria for the end point of tool life. In addition, it describes a procedure to be followed in running tool life tests. The recommended standard tool geometry is shown in Table 1, herewith, the recommended standard cutting conditions are shown in Table 2, and the recommended standard

criteria for end point of tool life are shown in Table 3.

Meanwhile, the Swedish Institute for Production Engineering Research, working in cooperation with Swedish manufacturing industry and Swedish cutting tool manufacturers, has developed a "bank" of highly standardized carbide and high speed steels. These are now available for purchase throughout the world and information on them is given in Table 4.

The Subgroup is now continuing with standardization of the various conditions used and anticipated to be used in the Cooperative International Research Program of the Group of Experts on Metal Cutting. Standardization of terminology is now nearly complete for the single point tool life testing and plans call for extending this to cover other methods of machining such as milling and grinding. Plans also call for standardizing additional test methods (such as the quick stop method of preparing chip samples) and on establishing international machinability ratings and standard methods for statistical analysis of machining data and statistical design of metal cutting tests.

4.11 Subgroups on Grinding and Electrical Machining Processes

4.11.1 Grinding

This Subgroup completed a preliminary set of cooperative tests as a starting point for developing a program of Cooperative Research. The tests were carried out with two different grinding

wheels (AA 46-G8-V 40 and AA 46-J8-V 40), grinding the XC 45 steel (AISI 1045 steel) used in the first Phase of the Metal Cutting Cooperative Research. Six laboratories participated, two in the U.S.A. and one each in Japan, West Germany, Belgium, and France. These laboratories made measurements on density, modulus elasticity, and hardness of the two wheels, as well as forces, wheel wear and surface roughness in grinding. Each laboratory used its own preferred methods for measuring these quantities in order to determine what degree of agreement between different laboratories might be obtained by using this approach. Analysis of the results showed that rather poor agreement between the different laboratories resulted, demonstrating the need for establishing standard conditions for carrying out cooperative research in grinding. The Subgroup is now proceeding to develop a set of standard tests and measurements to be used in the Cooperative Research Program.

4.11.2 Electrical Machining Processes

This Subgroup continued its program of cooperative research in electrical discharge machining. Comparative tests made under roughing and finishing conditions, machining a Ni-Cr-Mo-V steel with a copper electrode have now been completed by most of the participating laboratories. It was found that those laboratories which used relaxation type (RC) power supplies, which do not provide independent control of the amplitude and duration of the current pulses, were not able to get comparable reproducible results between laboratories.

However, quite good agreement was obtained between those laboratories using controlled pulse power supplies. This is demonstrated by the results discussed in the following paragraph.

Four laboratories have completed the first set of cooperative tests with the pulse type generators and reported their results, namely, the Technical University at Aachen, Germany; Chalmers University at Gothenburg, Sweden; the Technical University at Delft, The Netherlands and the Philips Company in Eindhoven, The Netherlands. The results of these tests are shown in Tables 5A and 5B, while Table 5C provides a description of the equipment used by these different laboratories in running these tests. As may be seen from Tables 5A and 5B, two sets of tests were run, the first being a finishing test with a pulse energy of approximately 10 milli-joules, a pulse current of 20 amperes, a pulse time of 25 microseconds, and a cycle time of 100 microseconds; and the second being a roughing cut with a pulse energy of 100 milli-joules, a pulse current of 25 amperes, a pulse time of 200 microseconds, and a cycle time of 400 microseconds.

The results given in the lower portion of Tables 5A and 5B illustrate the fact that material removal per pulse in electro discharge machining is almost directly proportional to the energy per pulse. On the other hand, the amount of electrode wear per pulse depends mainly on the average pulse current and is little influenced by pulse energy or pulse time.

Encouraged by the relatively good agreement obtained

between different laboratories in this first set of tests, the Subgroup is now planning a more ambitious set of cooperative tests to study in some detail the influence of the various EDM parameters and the properties of the tool and work materials on the performance obtained in electro discharge machining with the aim of developing fundamental understanding of these.

5. NEW STATUS OF PLENARY GROUP UNDER OECD AEGIS

As of January 25, 1967, the CIRP-OECD Group of Experts on Metal Cutting was given a new status. In this new arrangement the Group will continue to operate under the aegis of OECD, but the CIRP will operate the secretariat for the group and no longer be dependent upon OECD for this service. As a result, participation in the Cooperative Research activities of the group will no longer be limited to member countries of OECD but will be world-wide.

The details of this new arrangement are set forth in the official statements attached as Appendix VI.

TABLE I

STANDARD ANGLES FOR THE TOOL IN HAND (TOOL ANGLES)

Cutting tool material	Normal rake γ_n	Normal clearance α_n	Cutting edge inclination λ	Cutting edge angle κ	Included angle ϵ	Nose radius
High Speed Steel	12	5	0	75	90	See Table 2 for Values of Nose Radius
	15	8	0	75	90	
	20	8	0	75	90	
Sintered Carbide	+6	5	0	75	90	
	-5	5	-5	75	90	
Ceramic	-5	5	-5	75	90	

TABLE 2

STANDARD CUTTING CONDITIONS

		<u>Condition 1</u>	<u>Condition 2</u>	<u>Condition 3</u>	<u>Condition 4</u>
Feed	in. per rev	0.005	0.010	0.016	0.032
	mm per rev	0.125	0.250	0.40	0.80
Depth of cut	in.	0.040 \pm 0.002	0.100 \pm 0.004	0.100 \pm 0.004	0.100 \pm 0.004
	mm	1.00 \pm 0.05	2.50 \pm 0.0	2.50 \pm 0.1	2.50 \pm 0.1
Nose radius	in.	1/64	3/64	3/64	3/64
	mm	0.40	1.20	1.20	1.20

(NOTE: It may not be possible to use the positive rake angle geometry for carbide tools - Table I - with Condition 4).

TABLE 3

STANDARD CRITERIA FOR END POINT OF TOOL LIFE

Tool Material	Type of Failure	Unit	Condition 1	Conditions 2 & 3	Condition 4
High speed steel	Flank wear (VB, Fig. 1)	in.	av. 0.008, max. 0.014	av. 0.020, max. 0.028	av. 0.040, max. 0.055
		mm	av. 0.20, max. 0.35	av. 0.50, max. 0.70	av. 1.00, max. 1.4
	Crater wear (KT, Fig. 1)	in.	0.004	0.008	0.012
		mm	0.10	0.20	0.30
or catastrophic failure, if not avoidable					
Sintered carbide	Flank wear (VB, Fig. 1)	in.	av. 0.012, max. 0.020	av. 0.020, max. 0.028	av. 0.020, max. 0.028
		mm	av. 0.30, max. 0.50	av. 0.50, max. 0.70	av. 0.50, max. 0.70
	Crater wear (KT, Fig. 1)	in.	0.004	0.008	0.008
		mm	0.10	0.20	0.20
Ceramic	Flank wear (VB, Fig. 1)	in.	0.006	0.012	0.012
		mm	0.15	0.30	0.30
	Crater wear (KT, Fig. 1)	in.	-	0.004	0.004
		mm	-	0.10	0.10

TABLE 4

INDEXABLE INSERTS FOR CUTTING TEST

Specification

All inserts are manufactured in the following dimensions:

Length x with (square)	12.7 x 12.7 mm (1/2")
Thickness	3.18 mm (1/8")

Sintered carbide (indexable inserts)

The carbide inserts are specially manufactured in selected grades representing the groups P10, P30 and K20.

Type	Designation SMS 986 and SMS 987)	Nose radius r mm	Price Skr/insert
Negative rake angle ($\gamma = -5^\circ$)	194.1-1621 P10	0.4	15
	194.1-1621 P30	0.4	15
	194.1-1621 K20	0.4	15
	194.1-1623 P10	1.2	15
	194.1-1623 P30	1.2	15
	194.1-1623 K20	1.2	15
Positive rake angle ($\gamma = 6^\circ$)	194.3-1621 P10	0.4	17
	194.3-1621 P30	0.4	17
	194.3-1621 K20	0.4	17
	194.3-1623 P10	1.2	17
	194.3-1623 P30	1.2	17
	194.3-1623 K20	1.2	17

The carbide inserts specified above are recommended in our Cutting test. The carbide inserts specified below are intended for tests where nose radius 0.8 mm are better than 0.4 and 1.2 mm.

Negative rake angle ($\gamma = -5^\circ$)	194.1-1622 P10	0.8	15
	194.1-1622 P30	0.8	15
Positive rake angle ($\gamma = 6^\circ$)	194.3-1622 P10	0.8	17
	194.3-1622 P30	0.8	17

High Speed Steel (indexable inserts)

The HSS inserts will be manufactured in a modified version of a standard HSS (date of delivering is not yet settled).

Type	Designation	Nose radius r mm
Positive rake angle ($\gamma = 12^\circ$)	HSS4.3-1621	0.4
	HSS4.3-1623	1.2

The inserts may be purchased from the distributor Sveriges Mekanförbund, Artillerigatan 34, Stockholm Ö, Sweden.

TABLE 5A

C.I.R.P.- O.E.C.D.

INTERNATIONAL INSTITUTION OF PRODUCTION ENGINEERING RESEARCH

Working Group E.

Table of results of cooperative tests on Electro Discharge Machining.

Workpiece : 56NiCrMoV7

Electrode : Copper

	symbol	unit	Institute			
			T.H. Göteborg	T.H. Delft	T.H. Aachen	Philips
pulse energy	Δ_f	mJ	12.6	10	11.25	11
average pulse current	i_f	A	22.8	22	16.7	17.6
average pulse voltage	u_f	V	22.0	23	27	24
average current	I_f	A	4.1			
average voltage	U_f	V	7.4			
pulse time	t_1	μs	25	26	25	25
period time	t_p	μs	125	125	108	71
duty cycle	t_1/t_p	%	20	21	23	35
mat. removal per second	v_w	mm^3/s	0.22	0.30	0.21	0.37
electrode wear per second	v_E	mm^3/s	0.085	0.103	0.12	0.068
relative electrode wear	$\lambda = v_E/v_w$	%	38.5	34	55.9	18.2
mat. removal per pulse	v_{WF}	$10^{-6} mm^3$	30.1	37.3	26	23
electrode wear per pulse	v_{EF}	$10^{-6} mm^3$	11.5	12.8	14.6	4.2
pulse frequency	f_p	kHz	8	8	9.1	13.9
effective pulse freq.	f_f	kHz	7.38	7.9	8.2	
relative effective freq.	$\lambda = f_f/f_p$	%	92	99	90	
polarity of electrode			+	+	+	+
roughness CLA	R_a	μm	5.2	5	5.2	5

date : January, 27th 1967.

TABLE 5B

C.I.R.P.- O.E.C.D.

INTERNATIONAL INSTITUTION OF PRODUCTION ENGINEERING RESEARCH

Working Group E.

Table of results of cooperative tests on Electro Discharge Machining.

Workpiece : 56NiCrMoV7

Electrode : Copper

	symbol	unit	Institute				
			T.H. G8teb'g	T.H. Aachen	Philips		
pulse energy	A_f	mJ	110	110	98		
average pulse current	i_f	A	23.6	23.3	23		
average pulse voltage	u_f	V	23.3	26	22		
average current	I_f	A	11.0				
average voltage	U_f	V	13				
pulse time	t_1	μ s	200	200	190		
period time	t_p	μ s	400	380	232		
duty cycle	t_1/t_p	%	50	53	82		
mat. removal per second	V_W	mm ³ /s	0.69	0.815	1.0		
electrode wear per second	V_E	mm ³ /s	0.172	0.29	0.96		
relative electrode wear	$\mu = V_E/V_W$	%	2.34	2.95	0.9		
mat. removal per pulse	V_{WF}	10 ⁻⁶ mm ³	271.5	359	232		
electrode wear per pulse	V_{EF}	10 ⁻⁶ mm ³	6.36	10.59	2.1		
pulse frequency	f_p	kHz	2.5	2.6	4.3		
effective pulse freq.	f_f	kHz	2.33	2.28			
relative effective freq.	$\lambda = f_f/f_p$	%	94.8	88			
polarity of electrode			+	+	+		
roughness CLA	R_a	μ m					

date : January, 27th 1967

INTERNATIONAL INSTITUTION OF PRODUCTION ENGINEERING RESEARCH

Working Group E.

ELECTRO-EROSION EQUIPMENT IN USE.

T.H. AAGHEN

Machine :
 Generator : AEG TO-6 (transistor)
 Servosystem : Digital, stepping motor.
 Discharge counting : Current-voltage logic, followed by a bistable multivibrator and moving-coil indicator.
 Current measurement : Coaxial resistor, $1\text{m}\Omega$, time constant $20\mu\text{s}$.

T.H. DELFT

Machine :
 Generator : Square-wave generator with delay-line, not commercially available.
 Servo system : Electro-mechanical.

T.H. EINDHOVEN

Machine : Massovia FE 3S
 Generator : Transistor-pulse generator, not commercially available.
 Servo system : D.C.-motor, controlled by a combined digital-analog system.
 Discharge counting : Current-voltage logic followed by a counter.
 Current measurement : Flat resistor, $70\text{ m}\Omega$, time constant 1 ns .

T.H. GÖTEBORO

Machine : Sparcatron JC 262
 Generator : Sparcatron SPF 80A, with new, not commercially available pulse generator.
 Servo system : Hydraulic.
 Discharge counting : Current-voltage logic, followed by a counter.
 Current measurement : Current transformer.

PHILIPS

Machine : Charilles Klereda D13
 Generator : Charilles Isopuls P2
 Servosystem : Hydraulic.
 Discharge counting : Estimated from oscillogram
 Current measurement : Coaxial resistor, $4,6\text{ m}\Omega$.

January 26th 1967.

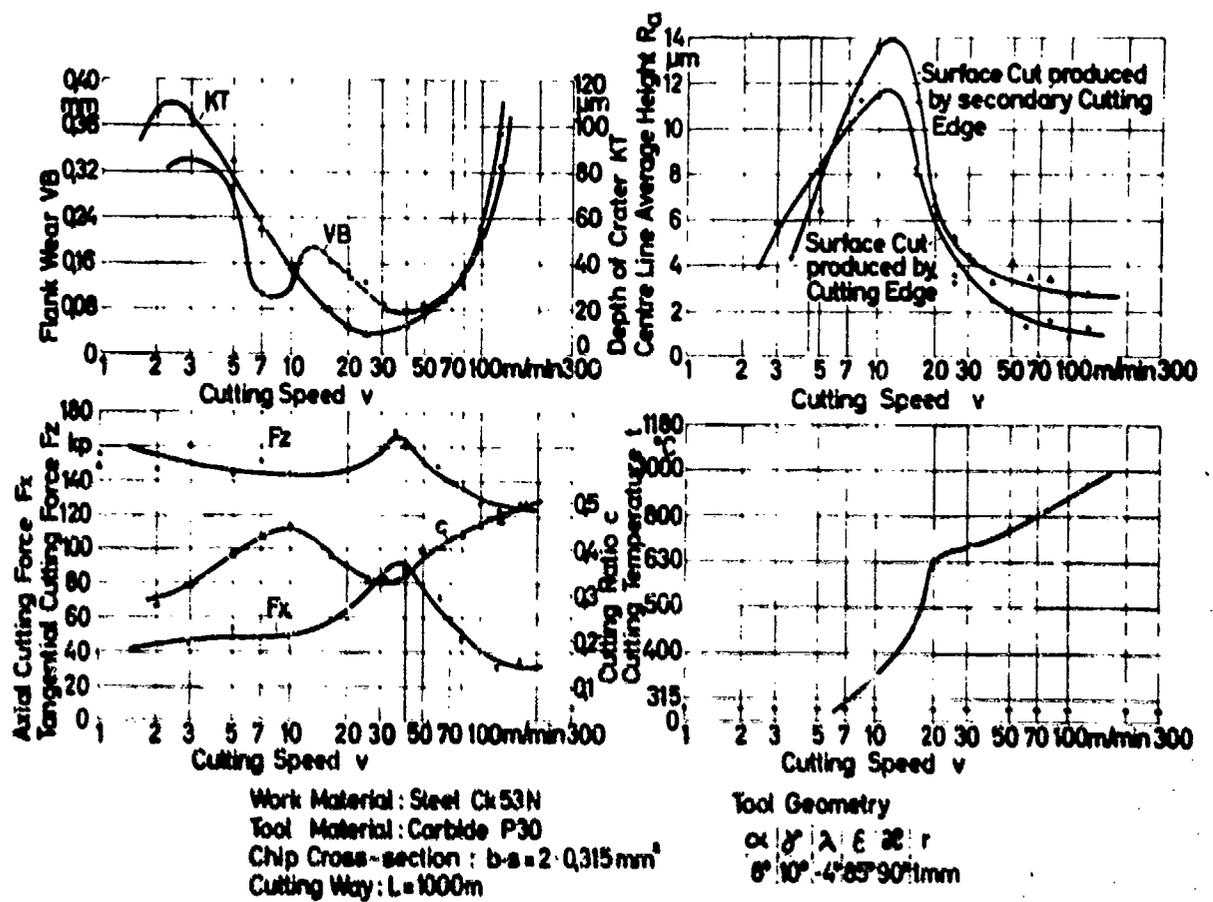


Fig. 1 Influence of cutting speed on the characteristic factors in the cutting process

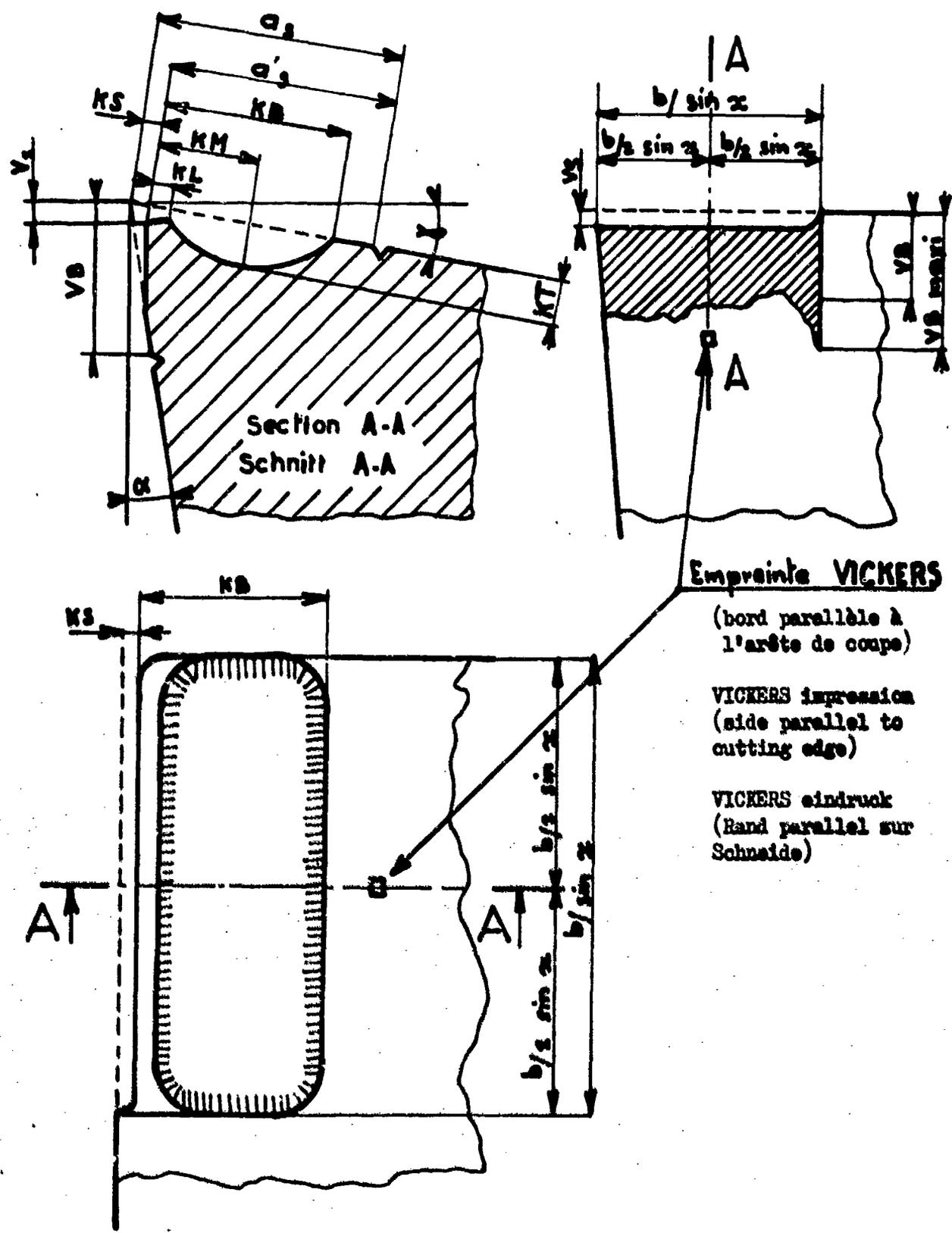


Fig. 2 GRANDEURS NORMALISEES DE L'USURE D'OUTIL

Tool wear

Werkzeugverschleiss

Plan de référence
Reference plane / Bezugsebene

Ligne de plus grande pente de la surface en dévissage - Maximum rake line in the clearance plane - Größte Steigungslinie in der Freiebene.

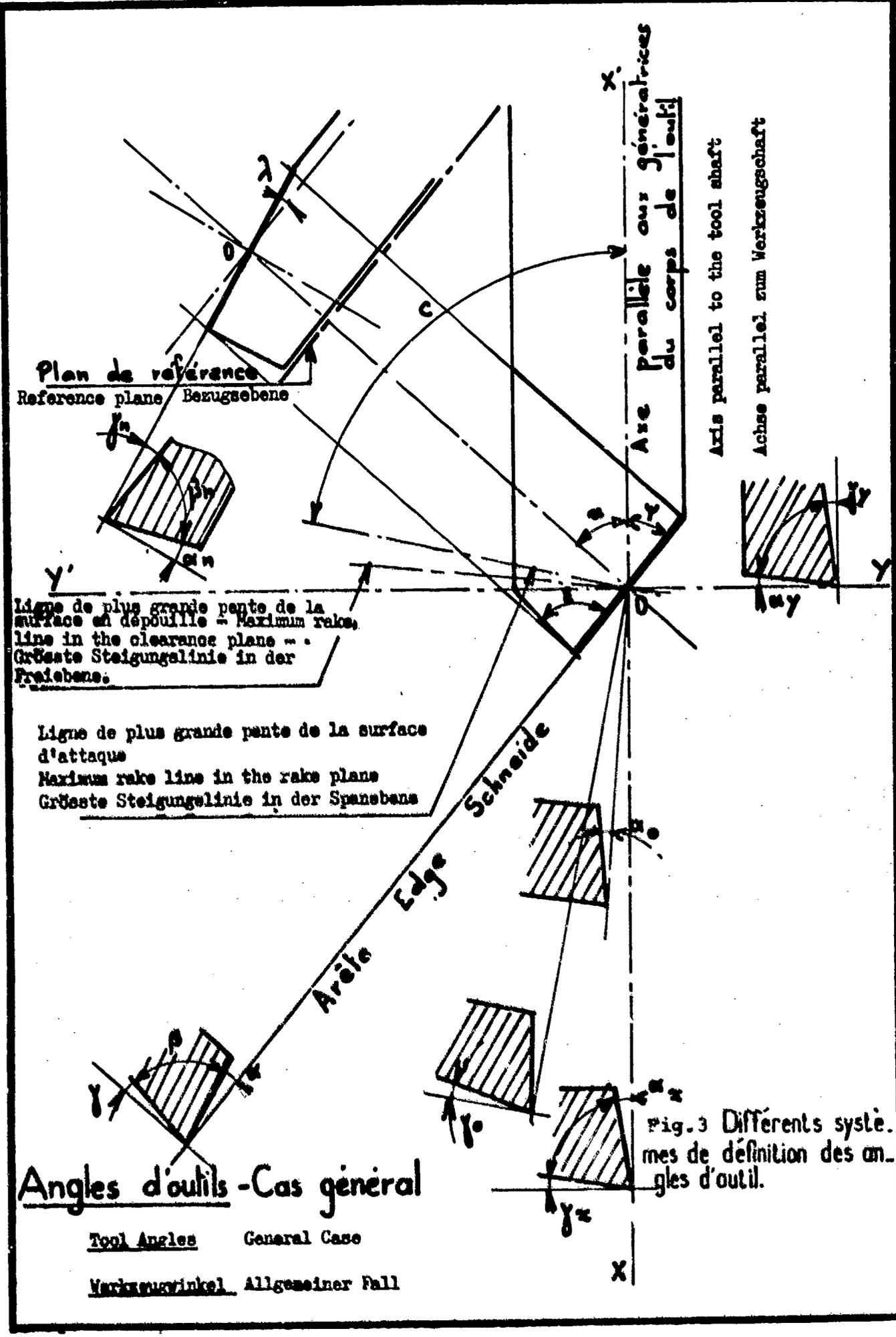
Ligne de plus grande pente de la surface d'attaque
Maximum rake line in the rake plane
Größte Steigungslinie in der Spanebene

Axe parallèle aux génératrices du corps de l'outil
Axis parallel to the tool shaft
Achs parallel zum Werkzeugenschaft

Angles d'outils - Cas général

Tool Angles General Case
Werkzeugwinkel Allgemeiner Fall

Fig. 3 Différents systèmes de définition des angles d'outil.



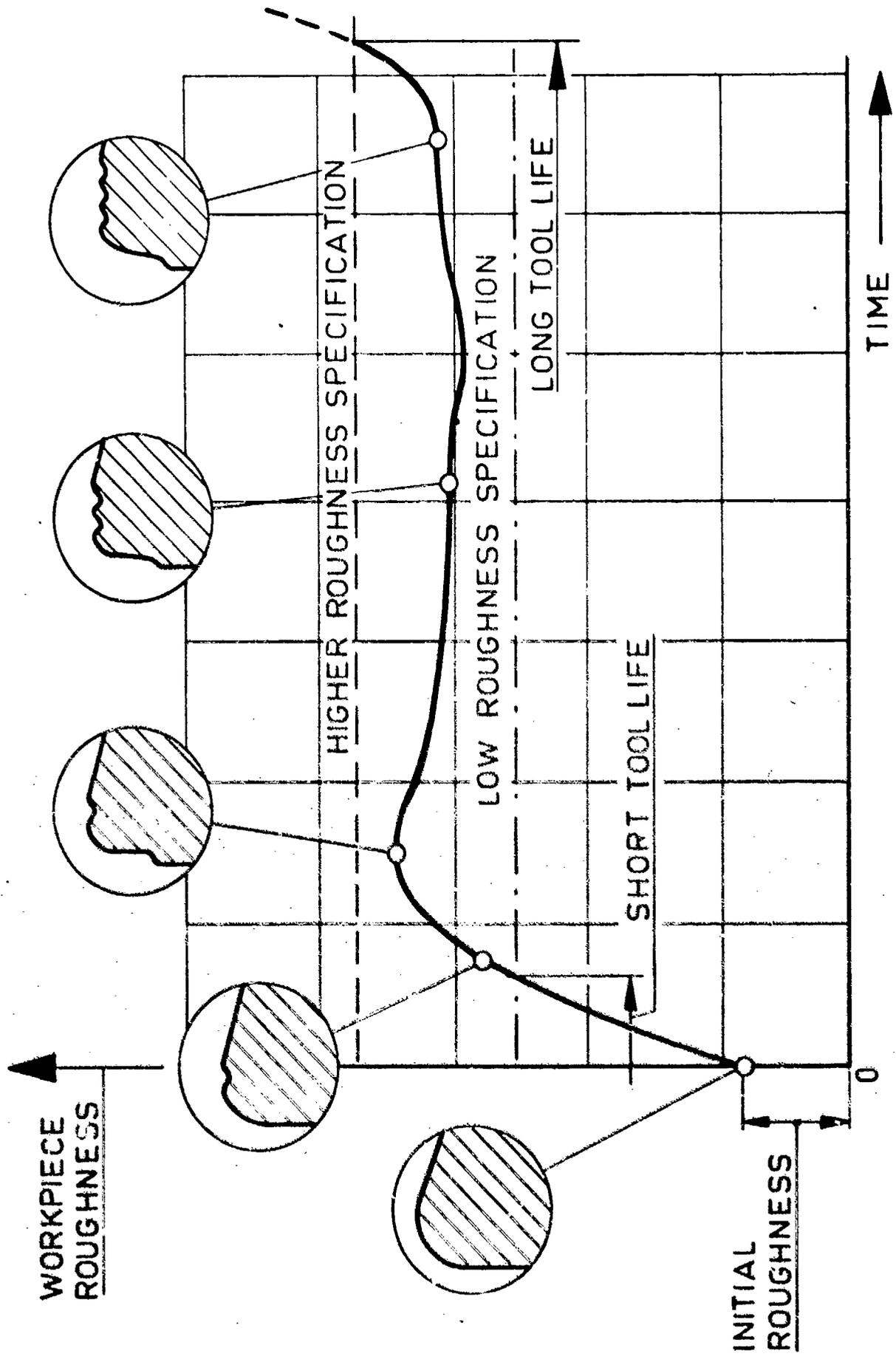
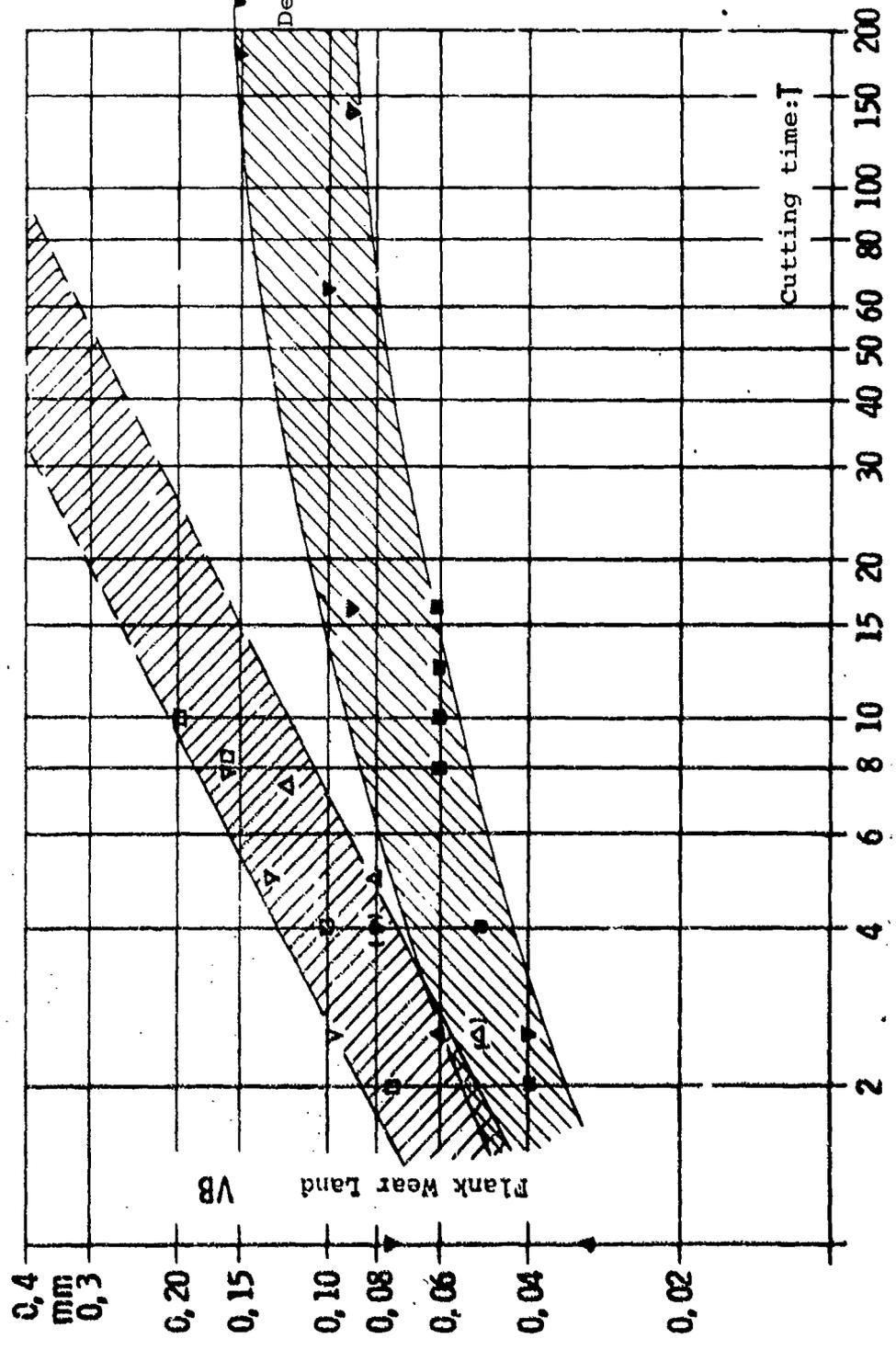


FIG. 4 CHANGES OF WORKPIECE ROUGHNESS AND TOOL PROFILE AS A FUNCTION OF TIME.

Figure 5

FLANK WEAR



Work Material: C 45 N (AISI 1045)
 Melt: \blacktriangledown \bullet \blacksquare \blacktriangle spec. deox. ∇ \circ \square \triangle \circ vac.
 Tool material: Carbide P10
 Cutting speed: $v = 200$ m/min
 Depth of cut: 3 mm
 Feed: $s = 0,25$ mm/U

\blacktriangledown Trondheim
 \bullet Cincinnati
 \blacksquare Aachen
 \blacktriangle Delft
 \circ Paris

CRATER WEAR

Work Material: C 45 N (AISI 1045)

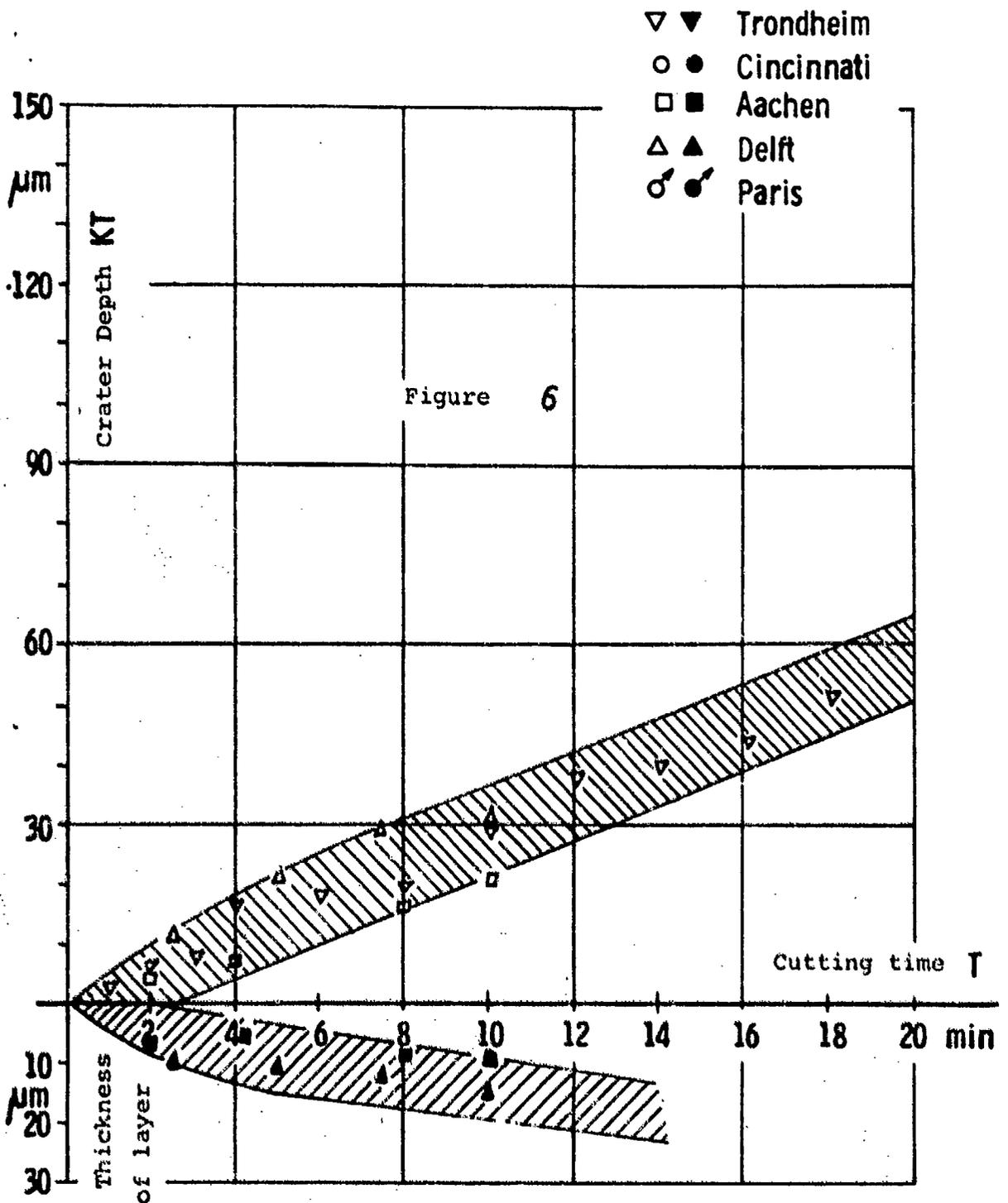
Depth of cut: 3 mm

Melt: \blacktriangledown \bullet \blacksquare \blacktriangle \circlearrowright spec. deox.
 ∇ \circ \square \triangle \circlearrowleft vac

Feed: $s = 0.25 \text{ mm/rev}$

Tool Material: Carbide P10

Cutting speed: $v = 200 \text{ m/min}$



APPENDIX I

LIST OF PARTICIPANTS

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(as of 25 January, 1967)

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APPENDIX II



ORGANISATION FOR ECONOMIC
CO-OPERATION AND DEVELOPMENT

INTERNATIONAL COOPERATION
IN SCIENTIFIC RESEARCH

seminar
on
METAL CUTTING RESEARCH

on 1st and 2nd September, 1966

at the
Château de la Muette
rue André-Pascal, Paris XVI^e

SEMINAR ON METAL CUTTING RESEARCH

*Results and future programmes,
merits and difficulties of international cooperation
in the field of Metal Cutting Research*

Organised by the

ORGANISATION OF ECONOMIC
COOPERATION AND DEVELOPMENT

Chairman

Professor Dr.-Ing. Dr.h.c. H. OPITZ
*Director of the Laboratory for Machine Tools
and Industrial Economics
at the Technische Hochschule, Aachen, Germany*
*Chairman of the OECD Group of Experts
on Metal Cutting Research*

Thursday, 1 September 1966

9:30 to 12:30 hrs.

1. SESSION

Conference Room C at OECD

Chairman of the Session

Professor F. Koenigsberger, Manchester U.K.

Welcome to the Seminar

OECD Directorate for Scientific Affairs

Opening on Behalf of the Metal Cutting Group

Professor H. Opitz, Aachen, Germany

Presentation and Discussion of the Following Papers

1. Introduction - History, Tasks and Achievements of the Group of Experts on Metal Cutting

*R. Weill, Ingénieur Militaire en Chef,
Laboratoire Central de l'Armement, Arcueil, France*

2. Studies of Machined Surfaces

*M.C. Shaw, Professor at the Carnegie Institute
of Technology
Pittsburgh, Pa., U.S.A.*

3. Mechanics of Cutting and Cutting Forces

*F. Eugène, Ingénieur Militaire en Chef,
Laboratoire Central de l'Armement, Arcueil, France*

4. Behaviour of High Speed Steel Tools

*E. Bodart, Professor at the University of Liège
Liège, Belgium*

Thursday, 1 September 1966

15:00 to 18:00 hrs.

Conference Room C at OECD

2. SESSION

Chairmen of the Session

Mr. F. Eugène, Paris, France

Presentation and Discussion of the Following Papers

5. Behaviour of Carbide Tools

*H. Opitz, Professor at the Technische Hochschule
Aachen, Germany*

6. Metallurgical Properties of Steels

*M.J. Pomey, Honorary Scientific Director
Usines Renault, Boulogne-Billancourt, France*

7. Plasticity of Steel Subjected to Cutting Stresses

*O. Svahn, Professor at the Chalmers Tekniska
Högskola
Göteborg, Sweden*

8. Cutting Temperatures

*M. Pasante, Centro Sperimentale del C.N.R.
Torino, Italy*

Friday, 2 September 1966

9:30 to 12:30 hrs.

3. SESSION

Conference Room C at OECD

Chairman of the Session

Professor M.C. Shaw, Pittsburgh, Pa., USA

Presentation and Discussion of the Following Papers

9. Statistical Programming

*H. Opitz, Professor at the Technische Hochschule
Aachen, Germany*

10. Unification of Test Methods

*R. Weill, Ingénieur Militaire en Chef,
Laboratoire Central de l'Armement, Arcueil, France*

11. Modern Manufacturing Trends, Needs and Optimization
Technology and Their Implications for Metal Cutting
Research

*E. Merchant, Director of Physical Research
The Cincinnati Milling Machine Company
Cincinnati, Ohio, U S A*

Friday, 2 September 1966

15:00 to 18:00 hrs.

4. SESSION

Conference Room C at OECD

Chairman of the Session

Professor H. Opitz, Aachen, Germany

**Discussion of Future Developments
and Research Activities**

Policy Statement of the Chairman

*H. Opitz, Professor at the Technische Hochschule
Aachen, Germany*

Discussion of Future Trends on Metal Cutting Research

Résumé and Conclusions of the Seminar

*F. Koenigsberger, Professor at the Manchester
College of Science and Technology,
Manchester, United Kingdom*

Participation

The Seminar will be attended by

- Members of the OECD Group "Metal Cutting"
- Members of the CIRP Group "Metal Cutting"
- Chairmen and Technical Secretaries of OECD Research Groups concerned with Mechanical Engineering
- Representatives of Governments, of Industry and of Engineering Associations designated by National Delegations to OECD
- Scientists and Engineers invited by the Secretary General of OECD.

Fees

The participation is free of charge.

Papers

Preprints of the papers to be presented will be sent to nominated participants free of charge in sufficient time before the Seminar.

Discussions

All participants are invited to comment on the papers to be presented.

Written contributions submitted to the OECD Secretariat at the latest one month before the Seminar will be duplicated for distribution at the beginning of the first session.

Proceedings of the Seminar

No written records will be taken during the sessions. All participants who contribute to the discussions are requested to submit their intervention in legible writing to the Chairman of the session concerned before the end of the 4th Session, i.e. 2 September 1966 18:00 hrs. Interventions which are not submitted in writing will not be contained nor answered in the final proceedings.

The proceedings will be sent to all participants as soon as possible after the Seminar free of charge.

In addition, a summary report of the proceedings will be published in technical magazines of various countries in the local language.

Languages

The official languages of OECD are English and French.

The papers will be circulated in the original language only - either English or French - but will be accompanied by summaries in both languages.

The presentation of the papers and the discussions will be simultaneously translated. The participants are requested to kindly use English and French only.

Hotel and Travel Arrangements

It is left to participants to book their hotel reservations and to arrange for their travels.

APPENDIX III

Group of Experts on Metal Cutting
Subgroup on Forces and Mechanics of Cutting

Meeting held 24 January, 1967, at 91 Boulevard
Exelmans, Paris 16, France

AGENDA

1. Progress report on the standard dynamometer
2. Final drawing up of the program of cutting tests on Ni-Cr and Cr-Mo steels
3. Measurement of cutting temperatures
4. Quick-stop tests in cutting
5. Distribution of tasks

DAS/CSI/66.358

RESTRICTED

Paris, 16th December, 1966

The Director for
Scientific Affairs

to

Members of the Plenary
Group on Metal Cutting
/copy to Members of the
Committee for Research
Co-operation and Heads of
National Delegations/.

Or. Fr.

DIRECTORATE FOR SCIENTIFIC AFFAIRS

COMMITTEE FOR RESEARCH COOPERATION

Group of Experts on Metal Cutting

9th Plenary Meeting of the Group of Experts
on Metal Cutting to be held 91, Bd Exelmans, Paris 16e
on 25th January, 1967 at 10 a.m. and 3 p.m.

Draft Agenda

1. Opening of the meeting by a representative
of the Directorate for Scientific Affairs.
2. Approval of the draft agenda. DAS/CSI/66.358
3. Approval of the minutes of the 8th meeting
of the plenary group. DAS/CSI/66.37
4. Results of the Seminar on Metal Cutting
held on 1st and 2nd September 1966 in Paris
(Mr. Weill).
5. Preparation of the second stage of coopera-
tive tests (Mr. Weill).
6. Results of the tests on specially deoxydised
steels (Prof. Opitz).

7. Results of the statistical evaluations by Mr. Lorenz (Prof. Opitz).
8. Standard dynamometer (Mr. Eugène).
9. Tests of stage 2
 - Inspection of materials (tools, steels) (Mr. Pomey).
 - Sub-Group "Mechanics of cutting and cutting forces" (Mr. Eugène)
 - Sub-Group "Behaviour of carbide tools" (Prof. Opitz).
 - Sub-Group "Behaviour of high speed steel tools" (Prof. Bodart).
 - Other sub-groups.
10. Unification of notations (Mr. Weill)
Standard testing of tools (Dr. Merchant).
11. New trends of cooperative research.
New groups (grinding, electrical machining, optimisation) (Mr. Weill).
12. Statement by the O.E.C.D. Secretariat on the independence of the working group.
Discussions and decisions concerning future cooperation.
13. Other business.

SEMINAR ON METAL CUTTING

SEMINAIRE SUR LA COUPE DES METAUX

List of Participants (1st September, 1966)

Liste des Participants (1^{er} Septembre, 1966)

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19.1.67

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Independence of O.E.C.D. Group of Experts
on Metal Cutting

1. O.E.C.D. Policy

Recent O.E.C.D. policy is directed towards promoting scientific research by establishing research groups and providing them with secretariat help on a short term basis, and to let the projects operate independently as soon as the continuation of their research activities can be assured outside of O.E.C.D. The active support of O.E.C.D. for any research group is now limited to two years.

2. Secretariat of Group "C" to CIRP

The group on Metal Cutting (Group "C") has been operating successfully under the Aegis of O.E.C.D. since 1960 and has completed the first phase of its programme in 1966.

In order to ensure continuity in this cooperative endeavour, the CIRP has stated its willingness to take over the secretariat for this group without financial assistance from the O.E.C.D..

The CIRP stressed its facilities to handle three languages (English, French and German).

3. O.E.C.D. Aegis

Although the CIRP would assume the secretariat responsibilities on behalf of the O.E.C.D., the Group's activities would still remain under O.E.C.D. aegis. This means that the Group continues to submit periodically to the CRC summarized progress reports and the work programmes and that it meets at the O.E.C.D. for the necessary discussions.

4. Participation in Research

Recognizing the different structures of CIRP and OECD, no limitation shall be set for participation : the CIRP shall accept cooperation of non-members of CIRP and non-member countries of OECD shall be able to participate in the cooperative research programmes.

CONCLUSIONS

Group of Experts on Metal Cutting has taken note of the OECD statement (pronounced by Mr. Hausen) and recommends that

- 1) the established cooperation be continued
- 2) the administrative secretariat be assumed by the CIRP as of the 25th January 1967.
- 3) the research programme be periodically submitted to the Committee for Research Cooperation in order to remain under the Aegis of the OECD.
- 4) the OECD be asked to facilitate at its Headquarters the discussions on the programme
- 5) no limitations be set for participation in the cooperative programme.

The group of Experts stresses that these recommendations conform with the OECD statement.