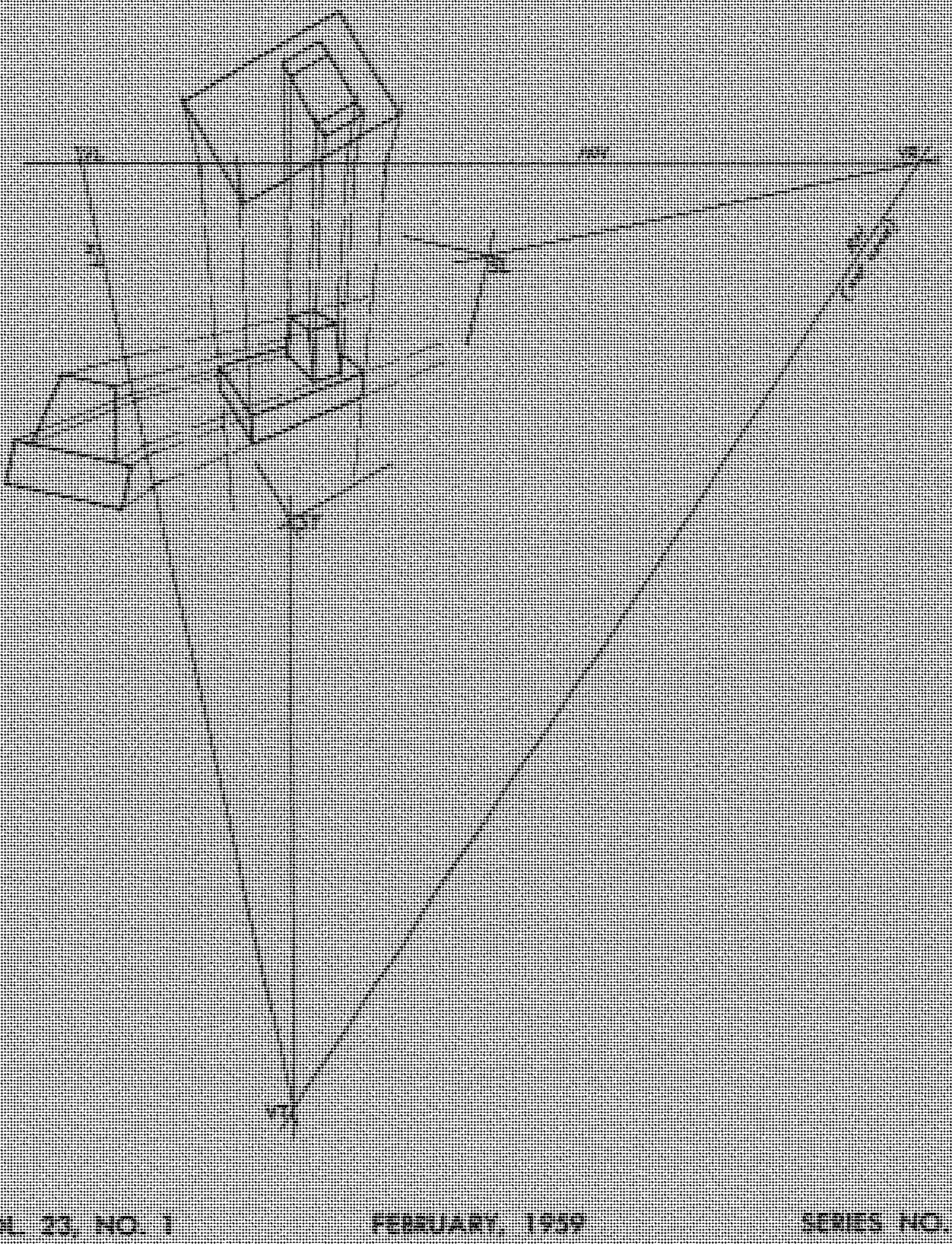
THE JOURNAL OF

ENGINEERING GRAPHICS



VOL. 23, NO. 1 FEBRUARY, 1959 SERIES NO. 67

PUBLISHED BY THE DIVISION OF ENGINEERING GRAPHICS
OF THE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

NEW . . . published in January

The fourth edition of Luzadder's

Fundamentals of Engineering Drawing

Considered by many a *standard* in the field, this engineering "best seller" — sales record: $1,000,000 — is now available in a new, improved, and completely revised fourth edition.

Through three successful editions "Luzadder" has helped to train more students in engineering drawing than any other text. In this new edition the author retains the tested and proved presentation that has won acclaim throughout the country. He also incorporates the latest drawing practices and standards approved by the ASA and SAE and accepted increasingly by modern industry.

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- A new chapter on pictorial sketching
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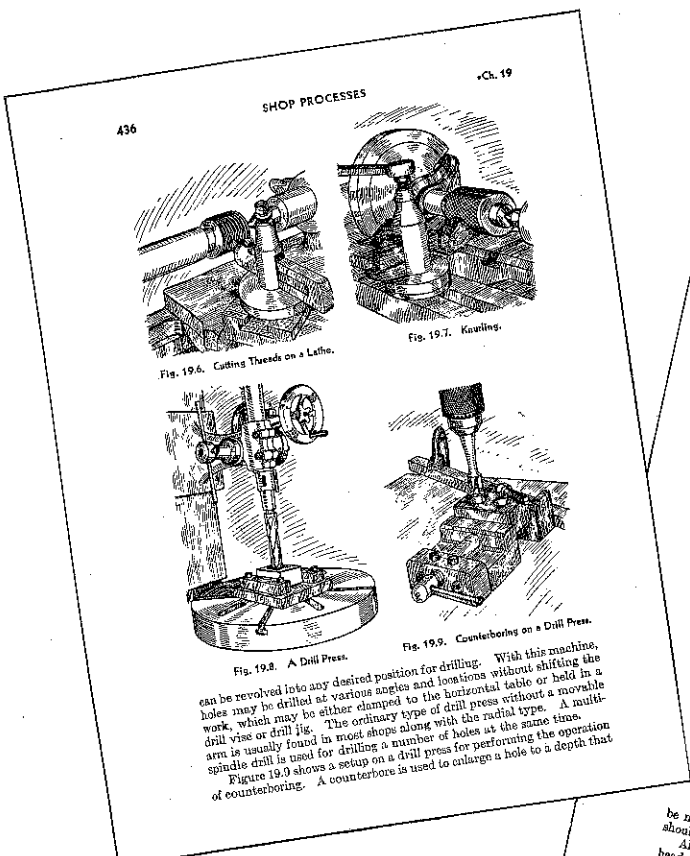


436 SHOP PROCESSES •Ch. 19

Fig. 19.6. Cutting Threads on a Lathe.

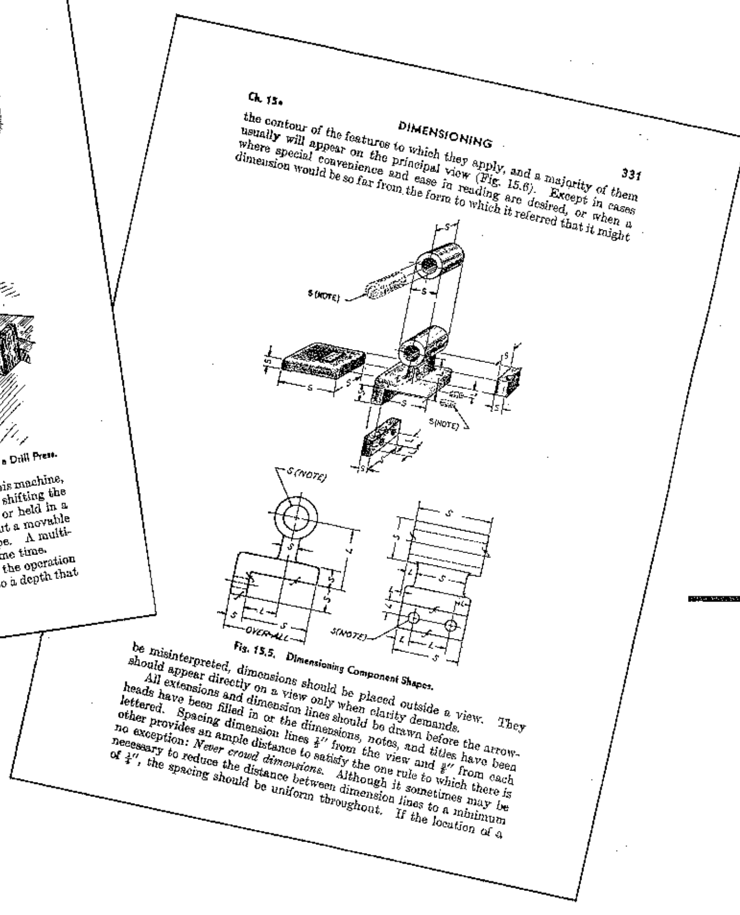
Fig. 19.7. Knurling.

Fig. 19.8. A Drill Press.

Fig. 19.9. Counterboring on a Drill Press.

can be revolved into any desired position for drilling. With this machine, holes may be drilled at various angles and locations without shifting the work, which may be either clamped to the horizontal table or held in a drill vise or drill jig. The ordinary type of drill press without a movable arm is usually found in most shops along with the radial type. A multi-spindle drill is used for drilling a number of holes at the same time.

Figure 19.9 shows a setup on a drill press for performing the operation of counterboring. A counterbore is used to enlarge a hole to a depth that



Ch. 15• DIMENSIONING 331

the contour of the features to which they apply, and a majority of them usually will appear on the principal view (Fig. 15.6). Except in cases where special convenience and ease in reading are desired, or when a dimension would be so far from the form to which it referred that it might

Fig. 15.5. Dimensioning Component Shapes.

be misinterpreted, dimensions should be placed outside a view. They should appear directly on a view only when clarity demands.

All extensions and dimension lines should be drawn before the arrowheads have been filled in or the dimensions, notes, and titles have been lettered. Spacing dimension lines $\frac{1}{2}$" from the view and $\frac{3}{8}$" from each other provides an ample distance to satisfy the one rule to which there is no exception: *Never crowd dimensions.* Although it sometimes may be necessary to reduce the distance between dimension lines to a minimum of $\frac{1}{4}$", the spacing should be uniform throughout. If the location of a

Designed for beginners, *Fundamentals of Engineering Drawing* is based upon a self-teaching approach that makes it uniquely easy to use as a guide through all phases of engineering drawing, regardless of background knowledge. The author has proved the value of this approach through years of successful usage with students at all levels.

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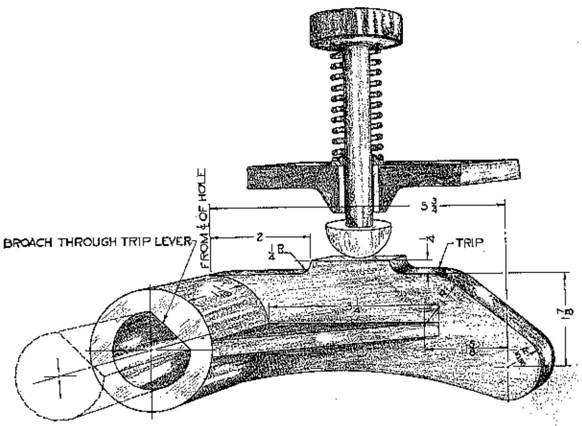
Meet the author—Warren J. Luzadder is well known as the author of *Graphics for Engineers; Technical Drafting Essentials, 2nd Edition; Problems in Drafting Fundamentals, Parts I and II;* and other titles. He has taught at Purdue University since 1930, and was editor of "The Journal of Engineering Drawing" from 1952-55. Mr. Luzadder was Chairman of the Engineering Drawing Division of the ASEE, 1957-58, and has served on such committees as Sectional Committee Y-14, Drafting Standards, American Standards Association.

768 pp. 6″ x 9″ Pub. 1959 Text price $7.50



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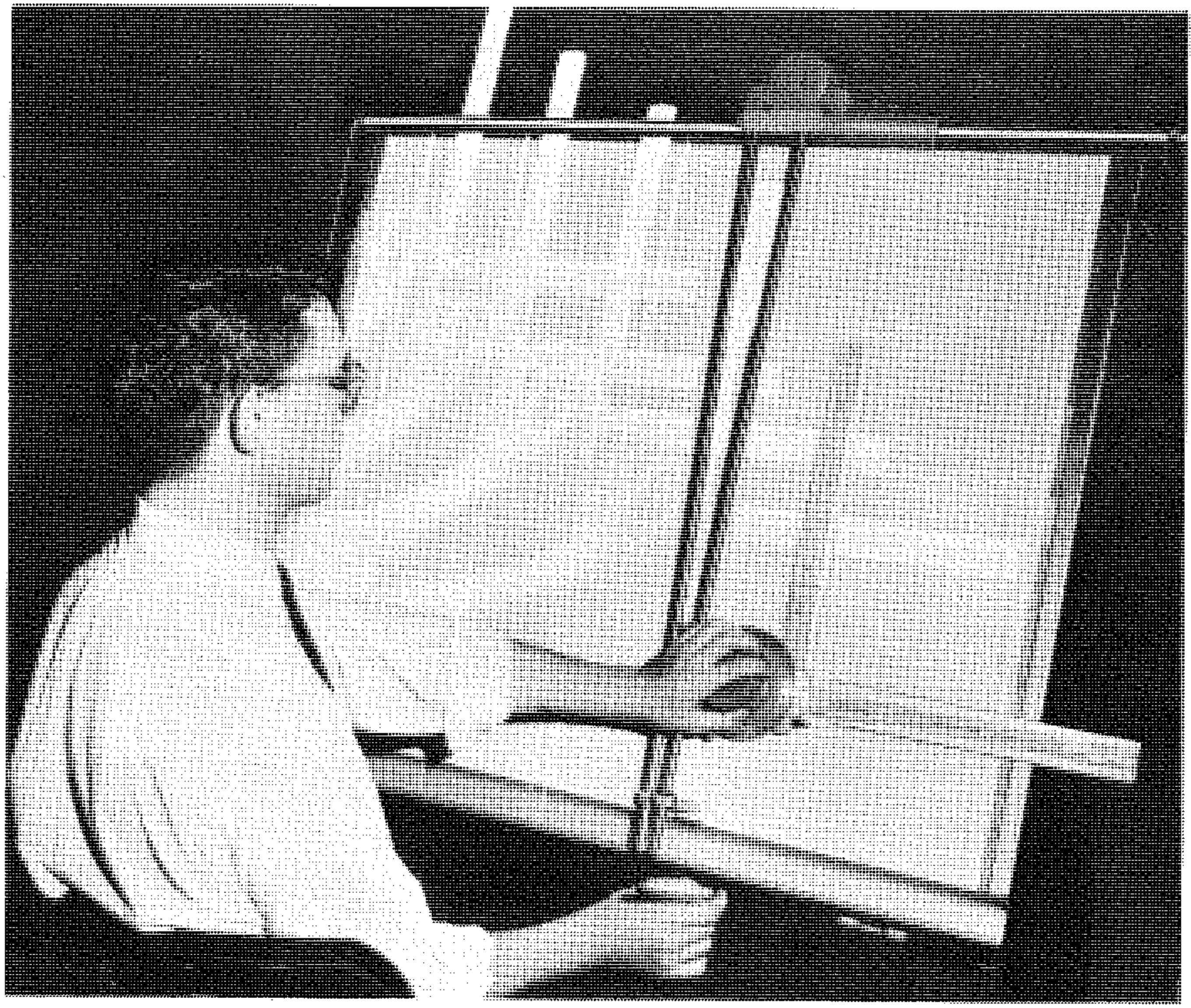

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and

MATHEW MCNEARY, Professor and Head, Department of Engineering Graphics, University of Maine

Fifth Edition, Ready In April

As in earlier editions, the purpose of this book is to teach the graphic analysis and solution of three-dimensional problems through application of the principles of orthographic projection. Major changes in this edition include a new format, changes in text and illustrations, new materials, new problems. An Instructor's Manual is available.

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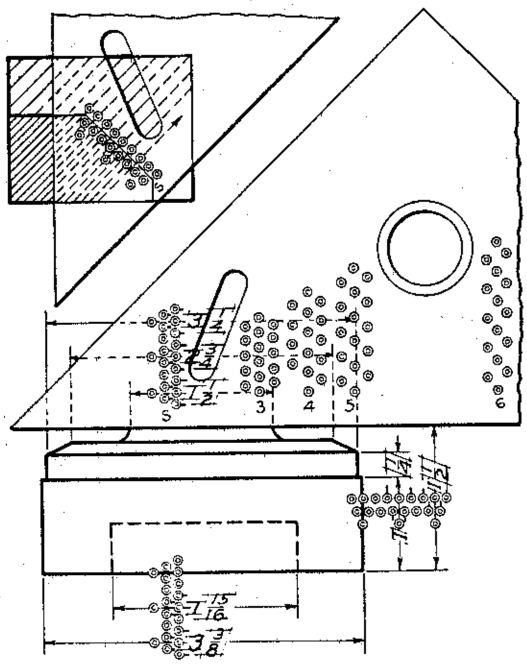

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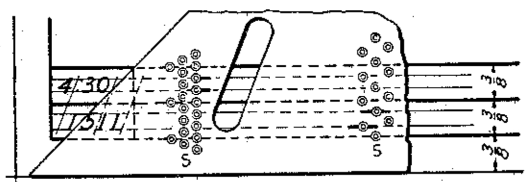

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CONTENTS

REVIVE GRAPHICS

In 1957, the Industrial Relations Committee of the Engineering Drawing Division of ASEE published a report supporting engineering drawing. It summarized opinion from practicing engineers--not educators. Degree-granting departments ridiculed the report. ECPD denied the scientific status of graphics and request for sufficient instruction time. Engineering colleges cut drawing credit in required courses to three, two, one--even to zero in a leading school.

When professional engineers have their opinion and desire flaunted by engineering educators, what recourse have they? One corporation has ceased interviewing at engineering colleges with little graphics. We hear that another corporation has withdrawn scholarships for the same reason. Direct action for graphics will come from an industry acquainted with specific curricular facts.

Supplication in the educational realm has lead to further debasement of graphics. Each of us should communicate the facts on reduced drawing in his college and others to corporation engineers and management. Contact engineering societies, such as ASME, ASCE and AIEE, who control ECPD. Graphics will revive.

ABOUT OUR COVER

"What is new about drawing?" We hear this remark from professors in the degree-granting departments. The cover of our November issue displayed one new aspect of drawing--a page from the new dimensioning standard.

The cover of this issue shows a new method of perspective. It was first published in an article by Professor Andre Halasz in the May, 1956 issue of the Journal. Those who ask "What's new?" are invited to examine that issue.

We are sorry for those engineers who do not know descriptive geometry--it has been removed from so-called scientific-engineering curricula in many colleges. They will not understand the scientific research and development of this <u>new</u> perspective method--explained so well by Professor Halasz.

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THE ENGINEER: LEADER OF MEN

During World War II, a Major noted that one of his companies excelled another in rifle marksmanship. Several Privates in Company A had become Expert and many were Sharpshooters. But in Company B there were only a few Sharpshooters, and no Experts! Why was one group of men performing so much better than another of equal caliber?

The Major found that the Lieutenant in charge of rifle marksmanship for Company A was an Expert himself. He personally demonstrated all phases of marksmanship to his men, answered all questions, and corrected each man on the firing line. For his rank, he was competent in other military tactics and knowledge. He was confident and decisive in his actions. His men were devoted to him and followed him with spirit and respect.

But in Company B, the Lieutenant could not hit the target. Rifle instruction was in the hands of noncoms of varying ability. All the Lieutenant could do was count scores, praise the few men who improved, and abuse the many who failed. His men detested him. He received reluctant obedience and performance in all company activities.

An officer is seldom armed with a rifle, or expected to shoot a rifle in combat. But to be a good leader, he should be able to shoot the rifle better than any of the men he intends to lead. He must know when and where to use the weapon, its capabilities and its limitations. If necessary, he must make the long shot himself. He must have similar competence with all weapons that he commands. The Lieutenant increases his knowledge and experience year by year, and may become competent to lead a regiment. He is not made a Colonel immediately, for he must first prove his ability in lesser capacities.

What has this to do with engineering education or engineering? Since the Evaluation of Engineering Education, we no longer teach or emphasize many practical aspects of engineering, particularly those dealing with hardware development. Courses such as forging, casting, model-making, surveying, machine processes, drawing and design have been omitted or reduced to impotency. We are more interested in the software development of the engineer by new emphasis on living-together courses. Are we educating engineers, like the Lieutenant in Company B, who cannot lead, who do not deserve to be followed, who have but the vaguest idea of the tactics of their subordinates?

In the old days, an engineer was competent to develop his ideas by his own drawing. We presume that our contemporary engineer will have drawing done for him by technicians. Will our engineer be a leader of the draftsmen, when they cannot receive from him the most elementary direction or understanding? Can they interpret or respect his naive scribbles? Who will solve the advanced problems in drawing? Does our engineer initial "approved" on the complex assembly drawing which he cannot begin to read? How many tests fail and delays come from his ignorance? Is our engineer a leader, or a frustrated, frustrating dreamer?

An officer seldom fires a rifle, but he should hit the target dead center when he does. An engineer, though he never draws a line in engineering research or production, should be an expert in drawing. Technicians who are guided by an engineer with superior knowledge in their specialties will respect and follow that engineer with enthusiasm, and help him create his dreams. We should return to education of engineers in the basic tactics of engineering.

ON-THE-JOB TRAINING IN DRAFTING AND DESIGN

By Tracy B. Nabers

Chrysler Institute of Engineering

Today, industry is short of well-trained technicians. "Technology is advancing at an accelerating pace....There is little hope that college enrollments in the immediate future will increase sufficiently to meet increasing industrial demand. The prospect is that the shortage will continue for several years". (1)

The drafting-and-design manpower shortage is most acute, both in quantity and quality. While engineering research activity has grown rapidly, design and manufacturing still require greater numbers of technically trained personnel.

Before World War II, we got along with inadequately trained draftsmen from high schools, colleges, shops and correspondence schools. Older, experienced men in the business could teach these beginners the tricks of the trade. Then, technology was only a "teen-ager". Now, industry has expanded at such a rate that our manpower requirements have outstripped our ability to meet them. An apprentice working under the guidance of a master is no longer adequate.

Graduates of engineering colleges have been conditioned against going on the drafting board. They have the impression that if they get on the board they will never get off. To the young man out of college, drafting appears to be an obstacle. If he spends any time on the drawing board, it is during a training period or orientation with company practices.

Not enough emphasis is placed on the relative importance of drafting and design to the over-all engineering problem. In the report "Survey on the Need for Courses in Engineering Drawing and Graphics", only 39 companies of 839 specifically mentioned that they start engineers in the drafting room or include a period of training on the drawing board. Officials of 52 companies complained about the reluctance of engineers to do board work, even when the young engineer was assured that his assignment would be of short duration.(2)

The shortage of engineers makes it possible for recent graduates to resist board assignments. To the young engineer this may seem unimportant, but the long-range consequences may be a detriment to industry and the engineer. Despite the trend of engineering graduates towards work other than design, design remains the basic element in engineering. We must continue to improve the quality of design.

In spite of our need for men, no one has obtained accurate statistics on the men required in the design field, annual replacements, manpower from various educational programs, or the kind of education and skills desired. Such statistics would have a significant bearing on our educational approach.

Three factors create jobs in drafting: Normal growth and expansion, promotion, and retirement. A draftsman needs a liberal education, and technical education including drafting, descriptive geometry, algebra, trigonometry, physics, and acquaintance with production processes. These requirements are not sufficient for higher drafting classifications. Tests indicate that our layout men and designers possess the aptitude of visualization to a high degree. They are also proficient at imagining and analyzing mechanical motion and applications of physical principles. Since most of our drawing courses do not develop these abilities to their fullest, the student does not have an opportunity to test his potential prior to investing several years of his working life. Some discontentment with a design career may stem from this factor.

Trends in the classroom and plant which influence engineering design activity are:

1. Engineers bypass the drawing board.
2. Reduction of drafting time in engineering colleges produces a young engineer unable to read complex drawings.
3. Complexity of design problems is increasing, but technical competence of draftsmen is not.
4. High school drafting courses may place more value on habits and attitudes than on drafting knowledge and skills.
5. High school graduates have too little training in technical subjects to be of immediate use as technicians.
6. Applicants for on-the-job training often do not have proper educational background--less than one-third of those interviewed have the potential to become design draftsmen.
7. Vocational training in high school is changing, with less specialization. Some educators would delay vocational training until the 13th and 14th school years.
8. Many drafting teachers have not had industrial experience.
9. Relatively few students are enrolled in technical institute drafting programs.

These statements suggest problems for educational institutions and industry. Their solution requires a reorientation of our viewpoint concerning what should be taught, where and by whom.

All major companies have drafting-and-design training programs. But industry needs the help of educators in preparing people for jobs. More men and women must be well-educated to provide top-flight creativity, and to perform the highly technical work required in this technical age. Our technical high schools and technical institutes furnish the basic education for draftsmen, but industry and colleges must train teachers, establish standards and programs. Industry regards personnel development as a major responsibility. Up-grading programs could increase the effective output of scientists and engineers by ten per cent. (3)

Following is a discussion of drafting and design up-grading programs, from the least to the most formalized.

Informal on-the-job experience. How does a trainee-draftsman ultimately reach the status of senior designer? The trainee often begins in the blueprint vault, or as a runner for design departments. Next he may go to the engineering records department where he becomes familiar with records for release and control of drawings.

In drafting, the trainee begins with elementary work such as making tracings or detailing simple parts. His work is criticized by the checker and others. Learning is superficial and inefficient. As his ability to draw progresses, more complex detail drawings are assigned. Proficiency in this work leads to drawing of small layouts. The trainee may then be classified as a junior layout man. He should acquire, either by himself or through formal training in night school, a working knowledge of descriptive geometry, mathematics, strength of materials, mechanics, fabrication of materials, manufacturing methods, and machine and machine-tool operations. With experience and self-education he may become a design draftsman. Should he advance higher, he would leave the ranks of the men on the board.

Apprenticeship type of on-the-job program. An apprenticeship has characteristics of both the formal and informal programs. Better programs have a well-organized sequence of job experiences. But too often the trainee is subjected to repetition of simple operations and unrelated assignments, because the major function of the design department is to produce engineering drawings. But excellent programs of this type do exist. For purposes of comparison, let us examine programs which are representative of each type of supervising authority.

Apprenticeship type program (Company Supervised). A typical design training program provides selected personnel with work experience and related study to acquire proficiency in detailing and to prepare for advancement. Larger companies have extensive training staffs for providing instruction. The period of training consists of 8000 hours of rotated work experience including 430 hours of classroom instruction. Instruction covers shop mathematics, geometry, trigonometry, compound angles, gearing, engineering algebra, logarithms, slide rule, descriptive geometry, layout problems, and classical physics. Classes are taught in the facilities of the training section. Classes meet for one hour per week for each course, partly on company time and partly on the trainee's time. An examination determines the applicant's basic drafting knowledge and his proficiency in drafting techniques.

Apprenticeship Type Program (Joint Supervision). Such a program is sponsored by the National Association of Engineering Companies in cooperation with the Bureau of Apprenticeship of the U. S. Department of Labor. They train personnel for design engineering and assure the independent engineering field of proficient workmen. High school education or equivalent is prerequisite. Apprenticeship consists of 8000 hours of work-on-the-job and related instruction. At the completion of four-years of training, a certificate is issued.

The assignments and hours for the four-year program are: Blueprint machine operation, 320 hours, filing, 240 hours, tracing, printing, chart making, standards, etc., 480 hours, detailing, 3000 hours, minor layout, 2000 hours, estimating and processing, 960 hours, plant layout, 328 hours, and related instruction 672 hours. Classes are in schools approved by the State Board of Control for Vocational Education. Courses studied are: Machine drafting, mathematics, engineering materials and processes, shop theory, handbook, algebra, industrial economics, jig and fixture design, geometry, trigonometry, die design, tool design, descriptive geometry, and several courses in mechanics.

The differences in the above apprenticeship programs are: Supervising authority, place of instruction for related subject matter, number of hours of instruction, and course offering.

Combined Vestibule and Apprenticeship. The purpose is to ease the shortage of engineers and to help fill the company's future needs. High school graduation is necessary, but two years of college is preferred. The term of training is twenty-six 40-hour weeks in the company school. Drafting instruction covers company techniques and standards. The student designs and details a small machine based on an old design. Work is for training only, but it is supervised by a project engineer; other project engineers act as customers. A student with two years of college is generally teamed with a high school graduate. Related instruction consists of electricity and its application to automated machines, lubrication, hydraulics, shop mathematics, logarithms, slide rule, comptometer, shop theory and standard parts. An apprenticeship of three and one-half years follows in production engineering, advanced design and cost estimating, and research and development. A trainee completing the program is classified as a detailer, and is encouraged to study for an engineering degree at night school.

Vestibule Program. Since 1945, on-the-job training in drafting has moved toward the vestibule type program. Schools are operated on company time, and in the facilities of the corporation. Drafting classes can be organized along the lines of the engineering departments and make use of the same procedures and problems.

Trainees accepted for this program are high school graduates with algebra, geometry, trigonometry, elementary physics, and six semesters of drafting or equivalent experience. Vestibule programs depend more on prior education and experience than do apprenticeship programs. At Chrysler, eighty per cent of those in our drafting-and-design training program have had pre-engineering in college or specialized design training in a technical institute.

The training period is twenty-six forty-hour weeks. Drafting assignments are organized in a series. The trainee works from layouts and master drafts which are furnished by engineering design departments. Problems are kept up to date. Related instruction is integrated with the drafting assignments and adjusted to the individual needs of the trainees. Typical subjects are drafting standards, standard parts, descriptive geometry, calculation of weight of parts, force analysis, developments, linkages, cams and gears, manufacturing processes, and engineering materials. A periodic review is made of the progress of the graduate of this vestibule program. He is encouraged to attend evening school at Chrysler Institute of Engineering or a local university to study advanced courses in mechanics, mathematics, physics, and structural design. Special courses are made available to those who reach higher drafting classifications. These classes usually meet for two hours immediately following the work day.

Training Program for College Graduate Engineers. We have noted that engineers bypass the drawing board. The de-emphasis of engineering drawing in most colleges is making communication difficult between the design draftsman and the young project engineer. Not many young engineering graduates today can read a complex drawing, such as an automotive body layout. For this reason, it has become necessary to include drafting training or layout interpretation courses as a part of on-the-job training of design engineers.

To illustrate the training of college graduate engineers, I have selected a plan recently published by General Motors, and also one phase of Chrysler's program.

". . .A typical training program for a college graduate engineer, entering a project engineering activity in a General Motors car manufacturing division is outlined below." (4)

> General orientation period - 2 weeks, specific work assignments in project engineering - 16 weeks, work assignments in related departments--motor engineering - 10 weeks, axle and transmission engineering - 8 weeks, drafting - 8 weeks, personnel, finance, manufacturing, purchasing and sales - 8 weeks.

Note that eight weeks is devoted to drafting. Some of the GM Divisions insist that this period be on the drawing board. The Fisher Body--GMI engineering co-op students are studying on the undergraduate level; however, they receive a considerable amount of board experience as well as the usual engineering drawing in school.

At the Chrysler Institute of Engineering, a thesis in design has been established. The student selects a project related to the automotive industry, and through his efforts presents a functional idea of potential value to the industry in general. With the widest possible field for the selection of a topic, a minimum number of restrictions are imposed on the design project. The design may be primarily analytical or on the other hand, an ingenious mechanism requiring numerous details. Six weeks is allowed for work on a project of this type, and an additional six weeks for writing a report. The normal requirements for a Thesis in Design are: Thesis report, design folio of assembly drawings and layouts, detail drawings, installation drawings, parts list or bill of materials, original data and computations book.

The Chrysler Institute of Engineering Evening School offers a special course in product design and production processes. The objective of this course is to give those involved in product design and development an understanding of production processes and their critical relationship to product design. The course covers all major production processes in the automotive industry. Each process is discussed by a speaker who is a specialist from our Staff Master Mechanics Office.

The variety and number of industrial training programs discussed in this paper may give the impression that industry is in the business of education. If this impression is true, it is only because training has become a necessary and vital program in our ever-increasing demand for competent personnel at all levels.

---

1. Council for Technological Advancement, Trends in Education and Utilization of Technical Manpower--A Critical National Issue, No. 5, page 1, 1200 18th St., N.W., Washington 6, D. C.
2. Survey on the Need for Courses in Engineering Drawing and Graphics, Industrial Relations Committee of the Engineering Drawing Division of ASEE.
3. Council for Technological Advancement, Trends in Education and Utilization of Technical Manpower--A Critical National Issue, No. 5, page 1, 1200 18th St., N.W., Washington 6, D. C.
4. Charles A. Chayne, Vice President, General Motors Engineering Staff, "Some Questions about Engineering Careers in General Motors", General Motors Engineering Journal, Vol. 4, 1957, pages 12-13.

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NEW MEMBERS OF THE DIVISION OF ENGINEERING GRAPHICS

The following new members of the American Society for Engineering Education have expressed their interest in the Division of Engineering Graphics. We are delighted to welcome them, and we invite them to join us in all our activities.

Naturally, we encourage subscription to the journal as so many new members have already done. We hope that both old and new members will give as well as receive contributions to engineering graphics by communication in the journal.

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Elliot Dembner, New York University
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Paul F. Eberling, Henry Ford Community College
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ANNOUNCEMENT OF
THE DESCRIPTIVE GEOMETRY AWARD

The Committee for The Descriptive Geometry Award of the Engineering Graphics Division is pleased to announce that the Douglas Aircraft Company has contributed $100 for an award in a Descriptive Geometry competition. The Committee has removed itself from the contest and has established the following rules for eligibility and standards of excellence.

1. The article should involve descriptive geometry in the solution of a problem or it should be an article on descriptive geometry.
2. The article must have been published in a periodical.
3. The article must have appeared in an issue between the dates of January, 1958 and December, 1958 inclusive.
4. The use of Descriptive Geometry must be an important feature of the article.
5. The article must be brought to the attention of the Committee. The Committee will naturally search diligently for all such articles but is not responsible for finding all such articles.
6. The article will be judged on the originality, resourcefulness, and effectiveness of its use of Descriptive Geometry. The drafting and the use of drafting aids, etc., should be competent, but are secondary considerations. Good quality sketches would be acceptable.
7. A majority of the committee votes received will determine the winner.
8. The winner will be announced at the Annual Dinner in June and the award will be made at that time.

The Committee is undertaking a search of the periodical literature. This is an extensive job and any suggestions of suitable articles or references will be greatly appreciated. You can help this subject and this committee by submitting references.

Kindly send any information regarding possible contest articles to any one of the Committee members.

Committee: Douglas P. Adams, Chairman
Mass. Institute of Technology

Jerry S. Dobrovolny
University of Illinois

Ivan L. Hill
Illinois Institute of Technology

IMPLIED SHOP RUN GEOMETRICAL TOLERANCES

By S. B. Elrod

Purdue University

Implied Shop Run Geometrical Tolerances means those tolerances of form which are understood to be consistent with good workmanship, and which will be met in the normal course of manufacture, even though not expressed on the drawing.

I'm afraid it will be some time before any real standardization is accomplished in this field. All I can do is give you some of the experience of those who have been striving to find some common denominator for implied shop run geometrical tolerances which will be acceptable to others.

One reason for the lack of progress in this field may well be explained by the letter from the standards engineer of a billion dollar industry as follows: "As you observe, the material on shop run tolerances is rare in published form. For the most part such data is limited to individual manufacturing departments and, in some instances, are closely guarded secrets inasmuch as there is fear on the part of the processing department that if the engineers got a good look at their machinery methods they might try to gobble up any leeway that the shop now enjoys". It has been said that we have reached the point where shop run tolerances of size can be standardized. This in itself would be quite an accomplishment, and I am looking forward hopefully to the day when it is finally done on an industry-wide basis. I suspect that in the logical course of events this must be first, for it appears that tolerances of size are more easily understood and applied by all concerned.

Except for the specialized features such as threads, splines, gears, etc., the only other item which seems to be pretty well standardized is drilled hole diametral tolerance. Tables are included in many standards indicating the attainable range of tolerances that are practical for specific processes. However, as fewer and fewer drawings nowadays contain process information this is a long way from being a standard.

Before we can get very far with any discussion concerning geometric tolerances we must first decide what is meant by the term. There are at least five recognized standards with which we are all fairly familiar, each of which defines geometric tolerances to a certain extent. These five standards are:

- British Standards Institution, BS308:1953,
- Canadian Standards Association, B 78.1-1954,
- MIL-STD-8A,
- American Standards Association Drafting Manual, section 5 (published Oct. 1957),
- Society of Automotive Engineers Dimensioning Standard, published, 1955 (Revised edition forthcoming soon).

In BS 308, clause 19, GEOMETRICAL TOLERANCES we find "a. DEFINITION. A geometrical tolerance is the maximum permissible overall variation of form or position about that shown on the drawing. In other words, it is the width of diameter of a tolerance zone within which the surface, or the middle plane or axis of the feature, is to lie. It represents the FULL indicator movement in cases where testing with an indicator is applicable."

The Canadian Standard B 78.1 copies the British Standard word for word plus the addition of the abbreviation (FIM) immediately following the phrase "full indicator". It is worthy of note that the British do not use this abbreviation, or this expression on their drawings.

MIL-STD-8A, section 4 is entitled POSITIONAL AND OTHER GEOMETRICAL TOLERANCING. "Paragraph 4.1.1 Scope.--This chapter deals with geometric characteristics such as flatness, straightness, angularity, perpendicularity, parallelism, concentricity, and position of a feature as related to its basic condition or to other features, and establishes appropriate symbols which shall be used where symbols are proper in lieu of or in conjunction with notes for indicating these relationships on drawings."

No wonder we have confusion. This is followed by seven subparagraphs under paragraph 4.3 dealing with each of these items separately, and followed by an illustration "APPLICATION OF POSITIONAL TOLERANCES" which seems to be an application of all seven of the items enumerated.

Things begin to clear up when we get into the American industry standards. From ASA Y-14, section 5, June 1955 proposal, paragraph 5.4.9.1, "TOLERANCES OF FORM. Tolerances of form state how far actual surfaces are permitted to vary from the perfect geometry implied by the drawing. Expressions of these tolerances refer to straightness, flatness, parallelism, squareness, angular displacement, symmetry, concentricity, roundness, and in a special sense, to position. Tolerances of form often affect one another; parallelism includes flatness or straightness, etc. Tolerances of form are also interrelated with tolerances that limit size or position. If all tolerances of form are stated as total tolerances, calculations for determining the effects of these interrelations are greatly simplified, and the expressions are not ambiguous. Statements of tolerances are therefore recommended to express limits of departure from form shown on drawings."

This is followed shortly by the statement that "When tolerances of form are not specified on a part drawing, it is commonly understood that an actual part will be acceptable if it is within the dimensional limits given, regardless of form variations." Essentially the same statement appears in the SAE standard, and in a somewhat different form in MIL-STD 8 and BS 308. Application of this statement to all except symmetry and concentricity is simple enough, but for problems of symmetry and concentricity it becomes a nightmare. However, for one who works with the SAE misnamed "Symbolic Notes" method for concentricity control it is relatively simple.

Since preparing this study ASA Y-14 section 5 has been published. I am very happy to see that the phrase "and in a special sense, to position" in paragraph 5.4.9.1 has been replaced with a very eloquent "etc." The rest of this paragraph has been rearranged and renumbered; however, I believe the meanings remain unchanged.

From the SAE dimensioning standard:[1]
"7.1 DEFINITION. A geometrical tolerance is the permissible variation in the specified form of an individual feature of a part. Shapes or forms into which material is fabricated are defined by the use of geometric terms, such as the plane (surface), a cylinder, a cone, a square, or a hexagon. The geometric definition assumes a perfect form, but because a perfect form cannot be produced, variations must be restricted if a specific quality is to be maintained. Geometric tolerances should be specified where appropriate for all requirements critical to functioning and interchangeability......... 7.3 TOLERANCES OF FORM. Tolerances of form define conditions of straightness, flatness, parallelism, squareness, angularity, symmetry, concentricity, and roundness. These tolerances specify maximum permissible variations from the desired form and the dimensional limits for all the errors mean that the entire surface concerned must be within the limits, not merely a point on the surface."

Having worked for four years with the committee which produced this latter standard I am inclined to be a little bit prejudiced in favor of this approach. However, I still am not completely satisfied with the definitions expressed herein, in that I still maintain that concentricity and symmetry are tolerances of position rather than of form. This is beside the point; however, the forthcoming proposed revision to the SAE standard definitely will not include concentricity under the heading of tolerance of form, but rather as one more aspect of positional tolerancing. Also, an attempt will be made to treat the ordinary coverage of symmetry in the same manner. Some organizations have for some years treated "concentricity" as a problem in positional tolerancing, even to the use of of the True Position note to control eccentricity. After all it matters not whether cylinders which make up a part are arranged along a common axis, or are scattered about on several.

Besides "flirting" with the subject in our committee discussions for the past few years I had the opportunity to spend a summer in the Engineering Standards group of a progressive industry working exclusively on the subject of geometric tolerancing, both expressed and implied.

In the case of implied geometrical tolerances our original aim was to produce a document for issuance to vendors and subcontractors, telling them what geometrical tolerances were to be expected in every case where no tolerance was specified. Many other firms have done a little bit of this -- usually incorporated with a large amount of material concerning definition and interpretation of notes and terms used on drawings. Notable among these are Westinghouse, General Electric, IBM and RCA. This latter item was part of the presentation of Mr. R. W. Pearson, printed in the May '56 issue of the Journal of Engineering Drawing.

Our first approach to the problem was to attempt to relate the degree of perfection of geometrical form to the specified surface roughness designation for the features involved. Tables were set up expressing permissible geometrical tolerances in terms of the size of the feature for surface roughness designations of 32 and under, 63 and under, and 125 and over. Omitting two of the eight classifications of the SAE listing, namely symmetry and angularity, left us with six basic classifications; at least one of these classifications was further subdivided into six parts, thus we ended up with fifteen tables of three columns each. It did not take long to find several drawbacks to this approach. First the mere size of the document made it almost prohibitive for the use for which it was intended. A second objection was the fact that in designing parts with a surface roughness designation of 32 or better very few such tolerances would be entrusted to the interpretation of such a document by most designers.

This approach paralleled, to a great extent, that of an article, "Geometric Tolerance", published in Machine Design, September 1955, by Mr. H. Blye, formerly of the American Machine and Foundry Company. One noticable difference was that in this article the geometrical tolerances were generally related to the process producing the feature. We felt that this was an outmoded approach since the practice of specifying shop processes on engineering drawings is rapidly disappearing.

One of the prime considerations for any company in setting up such a standard is the effect it will have on the total cost of the product. For an integrated organization the problem is of no great consequence since in such an organization the application of standards can be controlled and "run away inspection" prevented. By an integrated organization I mean one which produces all of the components of its own product, assembles and markets it as a complete unit, such as a typewriter, calculating machine, automobile, etc., which is sold on the basis of performance and dependability. On the other hand, a firm supplying component parts to others or building equipment to government contract and specifications--and who isn't nowadays--may find the application of such a standard a prohibitive factor if applied literally to every surface of every part produced.

Attempting to write a standard which would preclude such exhaustive application presents many difficulties. Attempts to categorize the degree of tolerance in terms of surface finish, processes, etc., have proven to be entirely too cumbersome. In preparation of the standard from which tables II and III and chart I are a part, two categories have been established in an attempt to cope with this situation. These two categories are described as follows: "column A, REGULAR TOLERANCE, applies to all primary parts. Primary parts include all highly stressed parts. Parts carrying special tolerances of ± .005 or less, and surface roughness designation of 40 or less. Column B, SPECIAL TOLERANCE, applies to secondary parts (having large tolerances ± .010 or more) and/or higher surface roughness designation." The intention of this classification being that the vendor or manufacturer should be able to determine whether close or liberal tolerances should be applied to a specific part on the basis of other controls which were stated on the drawing. This does not mean that a more liberal tolerance cannot be specified for certain features of a highly precisian part; conversely, very close tolerances can be specified by the designer on parts which otherwise would be classified as non-precision parts.

Another possibility exists, that of specifying nonfunctional surfaces of a part. It is implied that no controls other than the limits on the dimensions would apply to these surfaces even though some other limits were specified by such a standard. It is doubtful if this would be feasible with our present system of dimensioning and notes. However when, as, and if the widespread use of symbols for control of geometrical tolerances is accepted practice the extra labor involved in specifying such non-functional surfaces would be slight. Although we do have some agitation for the adoption of symbolic control of geometrical tolerancing I am satisfied that this is going to be a long time in coming, and we might as well forget about it for this generation. I understand from some of my colleagues who have considerable contact with international standardization through the ISO as well as through the normal trade channels, that some of the Eastern European countries are far ahead of us in this field, as well as in some other aspects of drawing standardization.

Many of these standards carry some additional borderline items, such as removal of burrs, limits defining sharp corners, etc. These are relatively unimportant items which we might as well ignore for the present and concentrate on eight basic classifications of geometric tolerances. Furthermore, we are concerned only with their application to the unique features of a part, and not to the somewhat standardized features such as threads, etc.

In table I the specifications of six companies for various applications of geometric tolerances are listed for quick comparison.

A large number of companies representative of the aircraft engine, automotive, machine tool, appliance and accessory industries were contacted for material. Of those who replied only these six had any standard which dealt with geometric tolerances. In abstracting these standards to make up table I all references to nonmachined surfaces except for straightness, squareness and angularity have been ignored. References to other tolerance for such parts were widely scattered and not considered worthy for inclusion here.

A study of the tabulation of the various standards in table I shows some rather interesting inconsistencies. One might rightly expect to find entirely different concept of tolerancing among different types of industries represented here; however, I'm afraid no correlation exists, for some rather wide variations occur within like industries. For example consider the first item tabulated, straightness of machined parts. Companies A and B and C usually considered as being in the field of precision manufacture, apparently have no specification for this item while companies D and E, both in a field usually considered as being much less precise, do specify tolerances for straightness. The difference here, however, almost approaches the fantastic, in that company E is ten times as close on its tolerances as company D.

It will be noted in this table that for several cases no limits are given nor is any table of tolerances shown. This is indicated by a broad X. Where nothing is indicated we may assume that it means that the maximum variation shall be within the limits of the dimension used to describe the surface, as per the provision of the ASA and SAE standards. This is illustrated by Figures No. 1 and No. 2. Figure No. 1 means that the cylinder can be to the maximum diameter or the minimum diameter shown, but in either instance it must be perfectly circular. Besides this, a cylinder of elliptical cross-section or a lobed shape as shown, is acceptable as long as neither the max nor min dimensions violate the limits specified on the drawing, and no sharp corners or ridges exist on the surface. These illustrations are greatly exaggerated, as is the custom.

Incidentally, the most exasperating shape is that produced by a centerless grinder, having an odd number of lobes. The "out-of-roundness", or variation in diameter of parts in this category cannot be detected by micrometer measurement of several diameters, as is suggested by some standards, but can only be determined by rotating the parts with indicators. Note that indicators is plural in this case, as one is not sufficient to do the job. (Note that MIL STD 8 ignores roundness).

Figure No. 2 illustrates the application of limits to the control of flatness, parallelism, and squareness, and should need no explanation. Referring back to table I we see that company A makes no specification for these three items, except to say that they are controlled only by the envelope, that is the limits on the dimension locating the surface. Reading across the rows for flatness, parallelism, and squareness of machined parts we find variations from .0005 per inch to .002 per inch, or in some cases the envelope of limits with a maximum rate, or some portion of the limit and a maximum rate. There appears to be almost no consistent pattern.

Figure 3 illustrates the allowable eccentricity of parts according to specifications of company A. The specifications for this example are "Two diameters, not specifically controlled for concentricity on the drawing, may have a FIR concentricity equal to the sum of the total tolerances on the diameters regardless of the finished size." It was found that this statement is not complete enough, and the example illustrated here was added with the statement "for example, two such diameters having total tolerances of.020 and .008 respectively may be eccentric .020 + .008 = .028 FIR." This assumes that the part is to be set up so that one of the surfaces indicates zero. When this condition exists the other may be out by .028 FIR. I have failed to mention col. C, which under some circumstances might mean exactly the same thing although it sounds much different. If the same part is set up on centers it is possible for each surface to have a FIR equal to the tolerance on that surface. Thus, if one surface indicated .008 and the other .020 FIR the actual eccentricity might be either the difference or the sum of the tolerances, .012 or .028 FIR. In either case the resulting part would be pretty "sloppy".

On the other hand I have heard of instances where, in the interest of perfect interchangeability, it is understood that all co-axial diameters for which no concentricity tolerance is specified shall lie within the envelope of size. This means that for external diameters of maximum size the FIR must be zero. Furthermore if any diameter is at minimum size it might have to meet the same requirements to fit the specification but not for interchangeability. Only the max envelope need be considered for purposes of interchangeability. This condition would be expressed by B S:308 as "CONCENTRICITY TOLERANCE ZERO, MMC."

In column D the specification is one-half the sum of the limit with a maximum of .005 FIR per inch in diameter. Column B simply gives a figure of .005 FIR. Column E gives a complex tabular presentation, Table C-4, which allows full indicator readings of from .0015 FIR up to .006 FIR on small machined parts, while column F specifies a flat .006 FIR.

One very important item which is too often overlooked is squareness of drilled and tapped holes. Company A provides a tabulation for drilled and reamed holes separately (table II). On the assumption that reamed holes require greater accuracy of directions as well as size and finish, a closer limit is set for those holes, ranging from 1° down to 20' with tolerances ranging from 2° down to 25' for drilled holes. Company B specifies 1° for all drilled and reamed holes of all sizes. Company C specifies 30' for all drilled holes and 10' for all reamed holes. Companies D and E have no specification covering this item. One might assume that in this case the angular variation is controlled by tolerances of size, or of position, however it is dangerous to make an assumption of this sort, as no two persons are sure to make the same one.

Another item of prime importance is the squareness of internal threaded holes, or commonly called tapped holes. Here again company A works out a rather detailed table III based on regular tolerances and special tolerances for less precise work, giving an allowable variation in terms of thread size. Chart I illustrates, in terms of the tangent of the angle, the provisions of this table. You will note a sharp increase in the angular allowance for threads under .50 inches in diameter. The greatest variation allowed, for a .190 diameter thread, regular tolerance, is approximately 54' when expressed in this form while the tolerance for a .50 diameter thread is approximately 28'. For diameters from .50 up to and including 2.00 the curve follows a nearly straight line, the tolerance allowed for a 2.00 diameter thread being approximately 12'. Company B specifies .005 per inch, which is approximately 17' for all sizes, and is the tolerance specified by for a thread of about 1.50 inch diameter in table III. Company C specifies 0°-30', which on chart I would apply to a thread between .3125 and .375 diameter. Companies D and F have no specification, while company E specifies 1°. Compared to companies A and B this sounds like very wide tolerances. However, I suspect that a great majority of their threaded holes would be of .250 diameter, or less. For companies A and B just the opposite is the case. Incidentally, table II is based very largely on the experience of one of the country's largest manufacturers of threaded fasteners which are prestressed to as much as 140,000 p.s.i. at assembly.

In preparing table I it was impossible to include all of the provisions for each of the items. In these cases reference is made to a table copied from the particular standard. Tables II through V were copied, while tables 4.11, B-4, C-3 and C-4 were photographically reproduced from their respective standards.

Some of the specifications of column A are not yet completely approved. They are being studied to be sure that they will not result in greatly increased costs. Conversely, one of the other standards was prepared several years ago to be applied only to drawings prior to that date. The assumption was that all new drawings were to be 100% complete; however this was found to be impossible and present-day drawings call out that standard.

Considering the constant improvement in machines, tooling, gaging and inspection methods it is obvious that much thought is going to be needed in this area.

With the publication of the ASA Y-14 Standard we have a relatively clear understanding among all the English speaking industries of this "newcomer" among us. Once the great mass of American industry has assimilated this material we may be in a better position to begin working toward some basis of agreement as to what Geometric Tolerances of Form are implied on any particular drawing to any particular feature of a part when none is specified. Even with this "firm foundation" some loopholes still exist. Only the ASA and SAE standards specifically state that in the absence of any control of geometric form the limits of the dimension defining the feature shall control. However, it is implied by most.

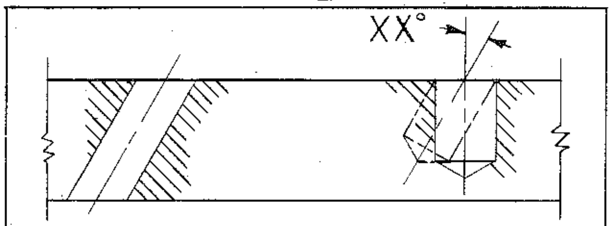
Also, the possibility that the SAE standard may be "off in the blue" again with only six categories of geometric form, relegating concentricity and symmetry to position where they belong, may create some new misunderstandings. I do believe that if these two items were removed from the listing of tolerances of form by all concerned it would go far toward eliminating some of the so-called inconsistencies in some of our practices.

TABLE I

COMPARISON OF IMPLIED GEOMETRICAL TOLERANCES SPECIFIED IN SIX TYPICAL STANDARDS

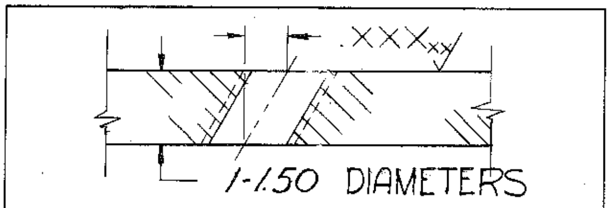
	A	B	C	D	E	F
STRAIGHTNESS	X	X	X	.005/IN	.0005/IN	.003FIR/IN
NON-MACH	TABLE V	X	X	X	TABLE V	X
FLATNESS	(ENV)	4.11	16√ .0005 32√ .001 63√ - 125√ .005 250√ .007 > 250√ .010	X	X	.003FIR/IN
PARALLELISM	(ENV)	.002/IN .015 MAX	< 3, .0005/IN 3 - 10, .0015 TOT 10 - 20, .002 TOT > 20, .003 TOT	1/2 LIMIT < .0005/IN	< 3, .001/IN, PLUS .0005/IN ABOVE 3 IN	.003 FIR PER IN
SQUARENESS FACE RUNOUT	(ENV)	< 5, .001 FIR PER IN DIA 5-12, .007 TOT > 12, .010 TOT	< 3, .0005/IN DIA 3 - 10, .0015 AT 10 - 20, .002 MAX > 20, .003 DIA	X	TURNED DIA .002 / IN STOCK DIA .004/ IN	.003 FIR PER INCH DIA
MACHINED	(ENV)	.002/ IN	< 3, .0005/ IN 3 - 10, .0015 TOT 10 - 20, .002 TOT > 20, .003 TOT	LIMIT < .001/IN	< 3, .001/IN, PLUS .0005/IN ABOVE 3 IN	.003 FIR
FORMED		± 30'	X	LIMIT < .003/IN	B4	X
DRILL & REAM	TABLE II	1°	DRILL 0°- 30' REAM 0°- 10'	X	X	X
TAP	TABLE III	.005/IN	0° - 30'		1°	
SPOTFACE, CBORE, CSINK	TABLE IV	X	X	X	X	.002 FIR/IN
ANGULARITY	X	X	00° - 30'	X	X	X
FORMED	X	NON-MATING ± 5° MATING ± 2°	X	X	X	X
CONCENTRICITY	FIR=SUM OF LIMITS	.005 FIR	FIR= LIMITS OF THAT SURFACE	1/2 SUM OF LIMITS. MAX .005/IN DIA	C4	.006 FIR
FORMED	X	(OR)CAST.032FIR				
THREADS	.005FIR	X	.006 FIR	X	X	X
ROUNDNESS	(ENV)	X	(ENV)	X	C3	X

TABLE II



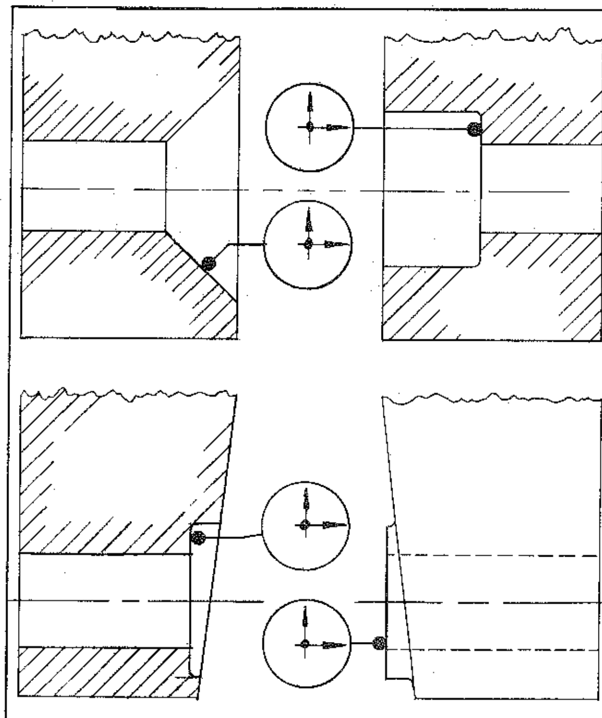
DEPTH	DIA	REAM	DRILL
To 1.00	.12-1.00	1°	2°
To 2.00	.12-1.00	45′	1°
To 3.00	.38-1.00	25′	30′
To 5.00	.50-1.50	20′	25′

TABLE III



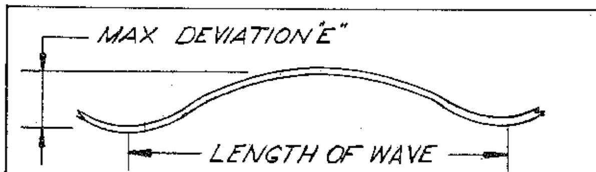
THREAD DIA.	A REGULAR TOL.	B SPECIAL TOL.
#10-.4375	.003	.005
.500-.5625	.004	.006
.625	.005	.006
.750	.005	.007
.875	.006	.008
1.000	.006	.008
1.250-2.000	.007	.008

TABLE IV



LARGEST DIAMETER	A* (REGULAR TOL.)	B* (SPECIAL TOL.)
.50	.001	.002
1.00	.002	.003
1.50	.0025	.004
2.00	.003	.005
2.50	.004	.006

TABLE V



LENGTH OF WAVE	MAX PERMISSIBLE DEVIATION "E" PER INCH OF LENGTH
0 - 12	.001
12 - 24	.002
24 - 48	.003
OVER 48	.004

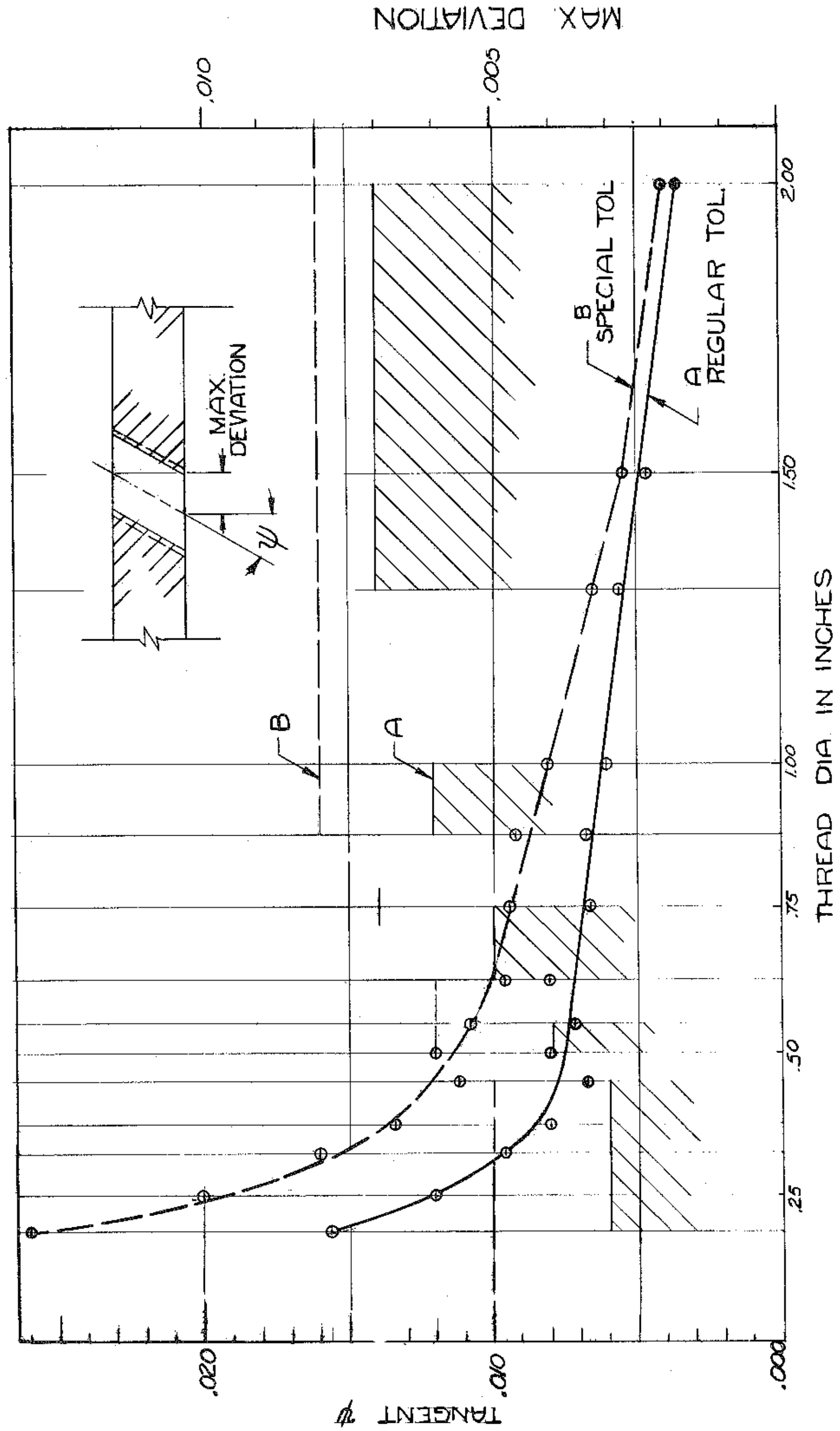
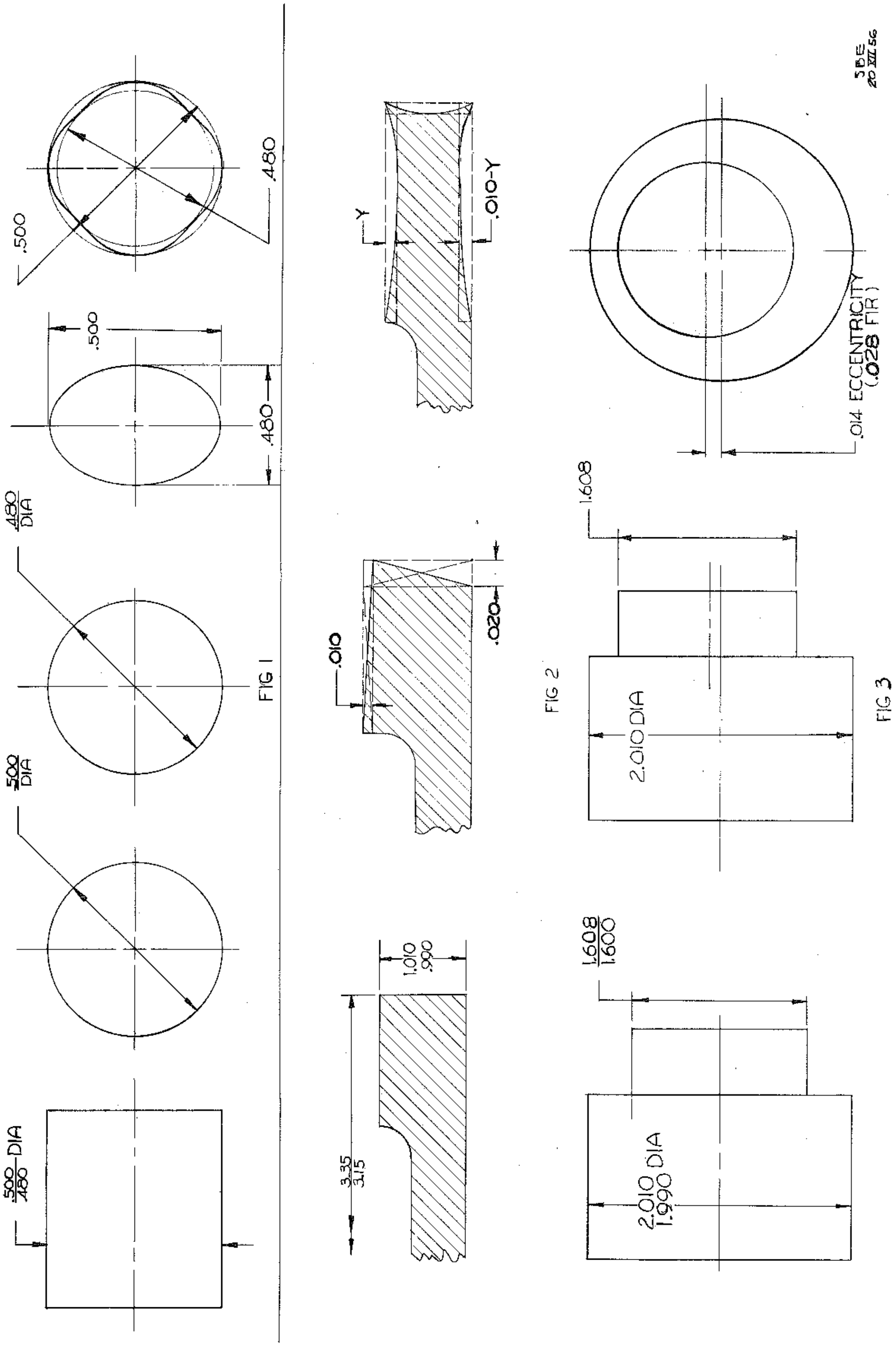


CHART I

TOLERANCES FOR SQUARENESS OF INTERNAL THREADS


.500/.480 DIA
.500/DIA
.480/DIA
.500
.480
.500
.480
FIG 1
3.35/3.15
1.010/.990
.010
.020
Y
.010-Y
FIG 2
1.608/1.600
2.010/1.990 DIA
1.608
2.010 DIA
.014 ECCENTRICITY
(.028 FIR)
FIG 3

4,11 FLATNESS - Machined Surfaces - No part of a machined surface will vary from a true reference plane by more than 'Y' for any length 'A'. (Fig. 22 and table 1)

Surface Roughness	Y	A
Up to and Including 32	.001	Up to and including 6 inches
	.002	6 to and including 12 inches
	.004	Above 12 inches length
Coarser than 32	.002	Up to and including 6 inches
	.004	6 to and including 12 inches
	.006	Above 12 inches length

TABLE 1

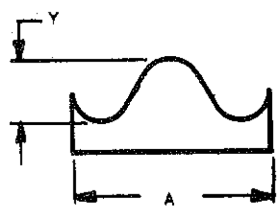


FIG. 22

B-4 **RIGHT ANGLE BENDS** (90° DIMENSION NOT SHOWN) SHALL BE SQUARE WITHIN VALUES GIVEN IN TABLE BELOW.

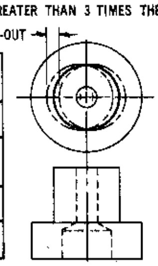
FORMED PORTION (USUALLY THE SHORTER SIDE)	UP TO 1/2	1/2 TO 1 1/2	1 1/2 TO 6	6 TO 12	12 AND OVER
MAX. ALLOWABLE VARIATION FROM SEQUENCES	.010	.020	1/32	3/64 per ft.	ADD 1/32 per ft.

C-3 **OUT OF ROUNDNESS** IS THE DIFFERENCE BETWEEN MAXIMUM AND MINIMUM DIAMETERS MEASURED AT THE SAME CROSS SECTION.

IF THE TOLERANCE ON TURNED DIA. IS:	THEN THE ALLOWABLE "OUT OF ROUNDNESS" SHALL NOT EXCEED
± .0005	.0002
± .001	.0004
± .002	.0006
± .005 OR MORE	.0008

C-4 **RUN-OUT (TOTAL INDICATOR READING) ON DIAMETER:** THE FOLLOWING TABLE APPLIES WHEN LENGTH OF PART IS NOT GREATER THAN 3 TIMES THE SMALLER DIAMETER.

TYPE OF DIAMETER	INSIDE DIA. TOL. UP TO .0025	INSIDE DIA. TOL. .0025 AND OVER	MACHINED OUTSIDE	STOCK OUTSIDE
INSIDE DIA. UP TO .0025	.0015	.006	.002	.006
INSIDE DIA. .0025 AND OVER	.006	.010	.006	.010
MACHINED OUTSIDE DIA.	.002	.006	.0015	.006
STOCK OUTSIDE DIA.	.006	.010	.006	—



A GRAPHICAL COMPUTATION OF HYPERBOLIC AND CIRCULAR FUNCTIONS OF A COMPLEX ARGUMENT

By D. Mazkewitsch

University of Cincinnati

Hyperbolic functions of a complex argument.

In electrical engineering problems, for instance in calculating transmission circuits, one has to compute hyperbolic functions of a complex argument. The construction of sinh (a + jb), cosh (a + jb) and tanh (a + jb) is given by Kennelly[1]. We present a method which enables one to compute in a simple way sinh (a + jb), cosh (a + jb) tanh (a + jb) as well as sin (a + jb), cos (a + jb) and tan (a + jb) by drawing the unit hyperbola and the unit circle only once.

Let us recall briefly the following. In the circular function the quantity t (in the expressions x = cos t, y = sin t) is twice the area of the circular sector AOB' (Fig. 1) in the circle $x^2 + y^2 = 1$. Similarly, in the expressions x = cosh t, y = sinh t, t is twice the area of the hyperbolic sector AOP in the hyperbola $x^2 - y^2 = 1$[2]. A circular sector may be expressed numerically in radians by

$$\frac{\text{length of arc of circle}}{\text{radius of circle}};$$

a hyperbolic angle may be expressed numerically in hyperbolic radians by

$$\frac{\text{length of the arc of hyperbola}}{\rho}$$

where ρ is the mean integrated radius of the sector AOP (Fig. 1)[1,3]. The unit hyperbolic angle, denoted by "hyp", encloses an area of one-half sq. unit or the same as the area of one circular radian. We recall further that if in the expression

$$\text{(1)} \quad \cosh x = \frac{e^x + e^{-x}}{2}; \qquad \sinh x = \frac{e^x - e^{-x}}{2}$$

x represents a complex argument x = a + jb, with j = -1, then the following relations are obtained:

(2) $\cosh(a+jb) = \cos b \cosh a + j \sin b \sinh a = p + jq$

(3) $\sinh(a+jb) = \cos b \sinh a + j \sin b \cosh a = p' + jq'$.

Construction of cosh (a + jb).

In a rectangular system of coordinates XOY (Fig. 1) plot the unit rectangular hyperbola $x^2 - y^2 = 1$ and the unit circle $x^2 + y^2 = 1$. Lay off the hyperbolic angle a equal numerically to the area of twice the hyperbolic sector AOP counterclockwise with OX as the initial line. Also, with OX as initial line lay off clockwise the circular angle b equal numerically to twice the area of the circular sector AOB'[4]. From P drop a perpendicular PQ on OX. Then OQ = cosh a, PQ = sinh a. From Q drop a perpendicular QB on OB' and from P a perpendicular PR on QB. Then ∢PQR = b

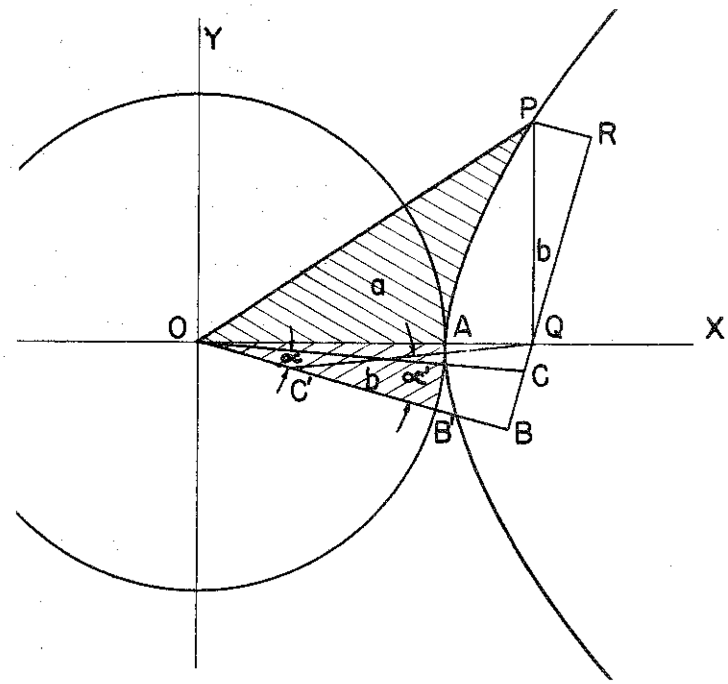


Fig. 1

and OB = cosh a cos b, PR = sinh a sin b. If now on the line BQ we lay off BC = PR we see, on comparison with (2), that OC represents the complex quantity cosh (a + jb), where OB is the axis of reals and BR the axis of imaginaries. OC is the modulus ρ and < COB the amplitude α .

Construction of sinh (a + jb).

From Fig. 1 we see that

QB = cosh a sin b, QR = sinh a cos b.

If again we consider OB as the axis of reals and BQ as the axis of imaginaries, and lay off BC' = QR, then QC' represents sinh (a + jb) with QC' its modulus ρ' and < QC'B its amplitude α' .

Construction of tanh (a + jb).

From (2) and (3) we obtain

$$\text{(4)} \quad \tanh(a+jb) = \frac{\sinh 2a}{\cosh 2a + \cos 2b} + j\frac{\sin 2b}{\cosh 2a + \cos 2b} = p'' + jq''$$

Lay off (Fig. 2) the hyperbolic angle POA = 2a hyps

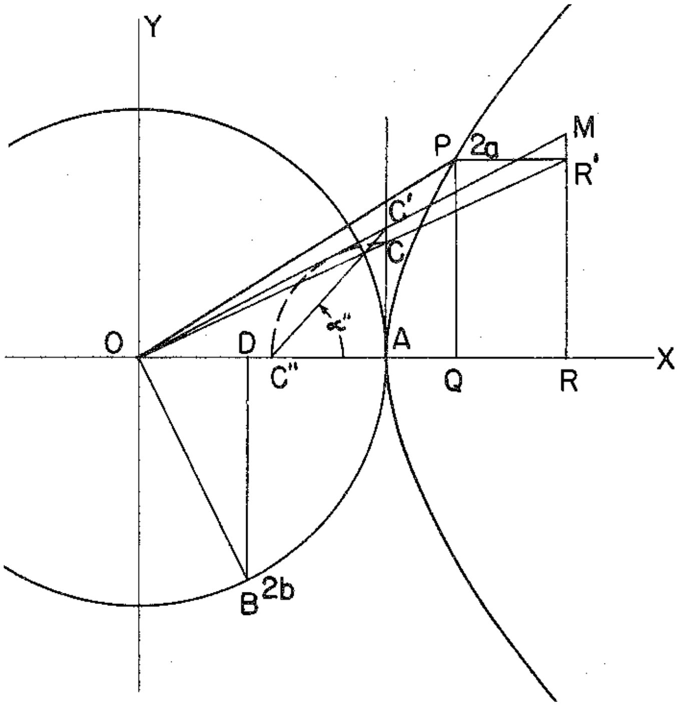


Fig. 2

and the circular angle AOB = 2b radians counterclockwise and clockwise respectively. Drop perpendiculars PQ and BD from P and Q on OX; we have OA = 1, PQ = sinh 2a, OQ = cosh 2a, OD = cos 2b. From Q on OX, to the right of Q, lay off QR = OD = cos 2b. At R erect a perpendicular to OR and lay off RR' = QP = sinh 2a. Then AC, cut off by OR' on the tangent to the hyperbola at A, is p" since ΔORR' is similar to ΔOAC.

Next on RR' lay off RM = BD = sin 2b and connect M with O, then on the same tangent at A we obtain the segment AC' = q". Rotating C into C" on OX gives the modulus ρ" = C'C" and the amplitude α" = $\angle$AC"C' of tanh (a + jb).

Circular functions of a complex argument.

If in

$$(5)\ \cos\phi = \frac{e^{j\phi} + e^{-j\phi}}{2},\quad \sin\phi = \frac{e^{j\phi} - e^{-j\phi}}{2j}$$

we let ϕ equal to a complex argument $\phi = a + jb$, we obtain

$$(6)\ \cos(a + jb) = \cos a \cosh b - j \sin a \sinh b$$

$$= p - jq\ ,$$

$$(7)\ \sin(a + jb) = \sin a \cosh b + j \cos a \sinh b$$

$$= p' + jq'\ .$$

From (6) and (7) we find

$$(8)\ \tan(a + jb) = \frac{\sin 2a}{\cosh 2a + \cos 2a} + j\,\frac{\sin 2b}{\cosh 2b + \cos 2a}$$

$$= p'' + jq''\ .$$

From formulas (2), (3) and (4) we see that the real part a of the complex argument enters only in the hyperbolic functions, while the imaginary part b enters only in the circular functions. The reverse is true for the circular functions as is seen from the formulas (6), (7) and (8). Hence the construction of cos (a + jb), sin (a + jb), and tan (a + jb) is made in the same unit hyperbola and unit circle, in the same way as for the hyperbolic functions, only a is now laid off on the circle and b on the hyperbola. The construction of cos (a + jb) and sin (a + jb) is evident from Fig. 3 which is self-explanatory, if one observes that

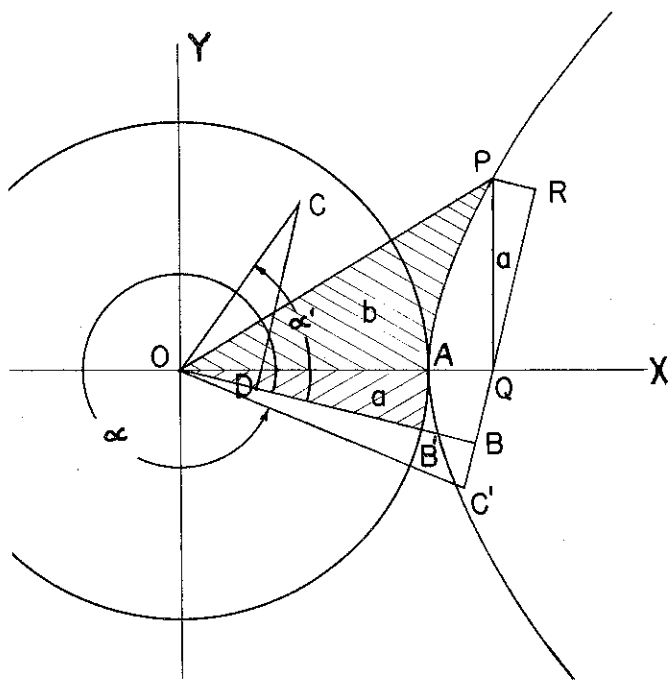


Fig. 3

BC' = PR = sin a sinh b, OD = BQ = sin a cosh b
DC = QR = cos a sinh b.

In computing the amplitude account has to be taken of the quadrant in which the complex number lies.

The method presented permits one to compute graphically the hyperbolic and circular functions of a complex argument by plotting on a stiff cardboard the unit hyperbola and the unit circle. On a thin paper laid over it one obtains easily any one of the functions sought by drawing four or five lines. The accuracy depends on the unit selected.

---

[1] A. E. Kennelly, "The Application of Hyperbolic Functions to Electrical Engineering Problems", pp. 1-9, 250-253, 1912.

A. E. Kennelly, "Artificial Electric Lines", pp. 6-10, 120-123, 1925.

[2] R. Courant, "Differential and Integral Calculus", p. 188, 1937.

[3] Wm. Nesbit, "Electrical Characteristics of Transmission Circuits X", Electr. Journ., pp. 257-261, 1920.

[4] If a or b are negative, they have to be laid off in opposite directions.

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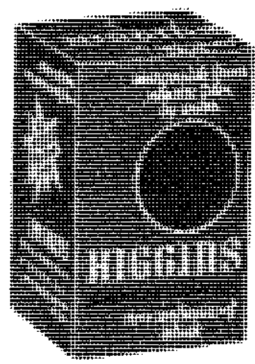

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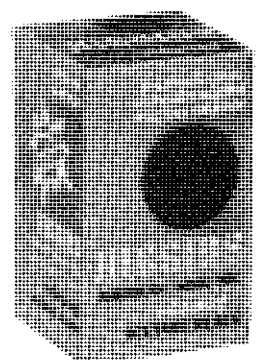

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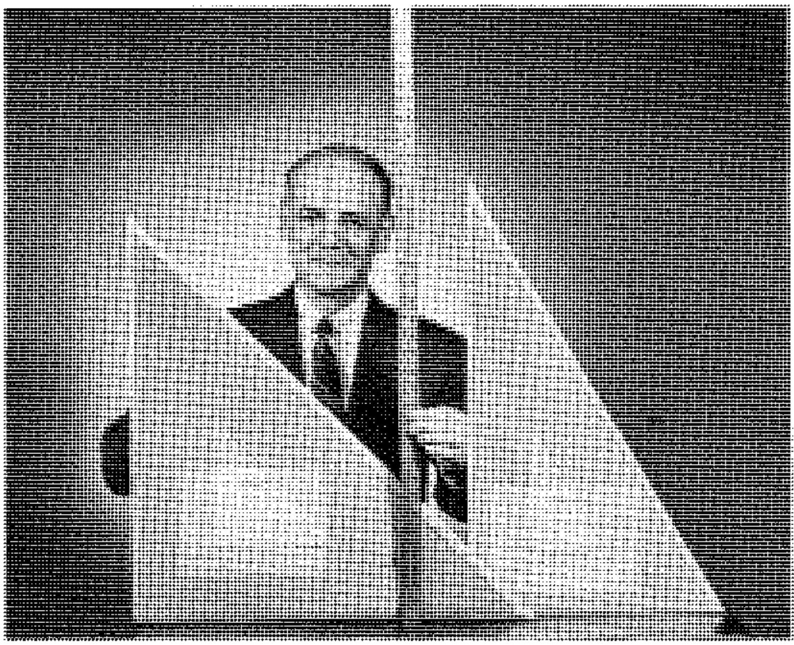

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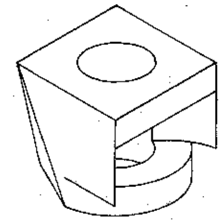

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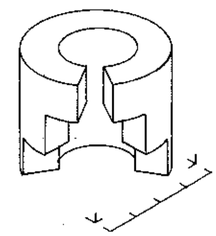

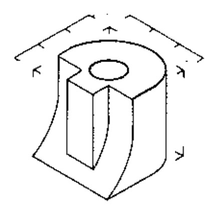

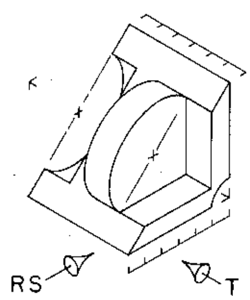

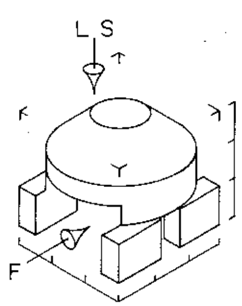

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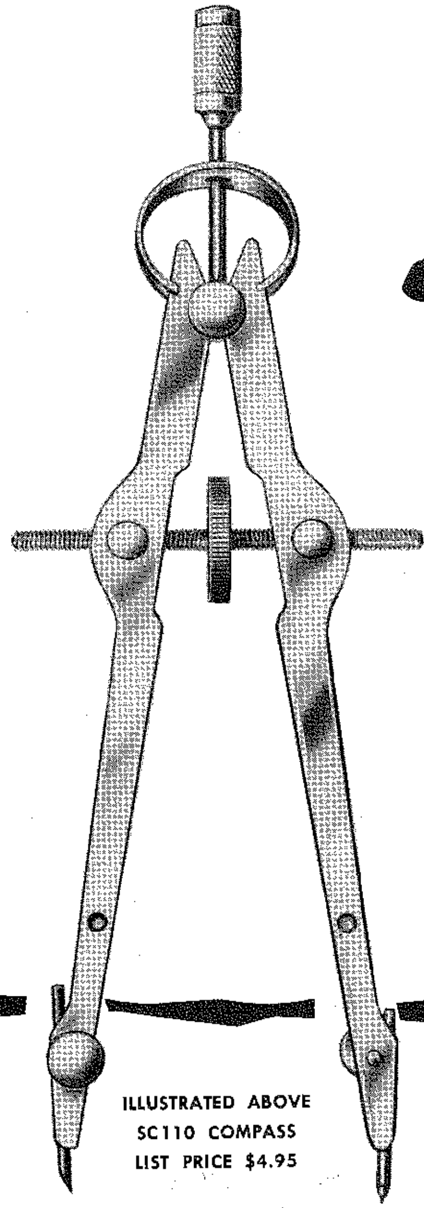

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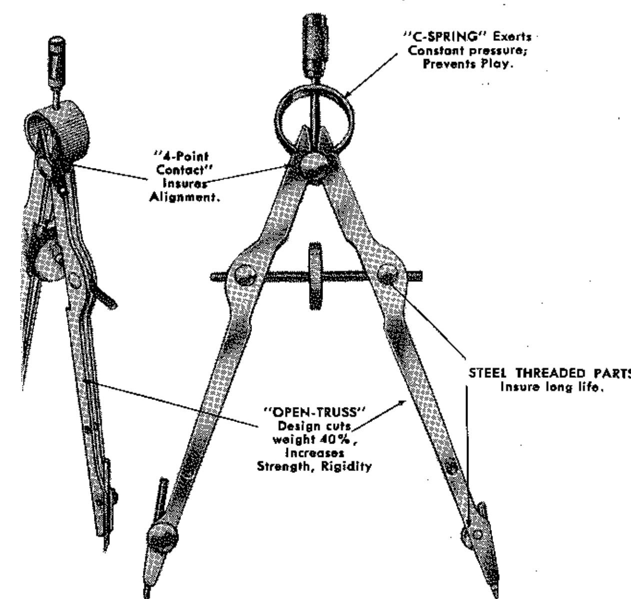

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