

Contents

<i>Chapter</i>	<i>Page</i>
PREFACE	v
LIST OF TABLES	xiii
1. INTRODUCTION	1
2. LINE-GRADUATED MEASURING INSTRUMENTS	9
ESSENTIAL PROPERTIES	9
Categories of line-graduated measuring instruments	
LINE-GRADUATED BARS, RULES AND TAPES	9
Limitations of length measurements by line-graduated rules – Accuracy of line-graduated bars and rules – Line-graduated reference bars – Line-graduated inspection bars – Line-graduated working rules – Graduated rule accessories – Steel measuring-tapes	
LINE-GRADUATED CALIPER GAGES	16
Essential elements and functions – Measuring sensitivity and accuracy of vernier type, caliper gages – The design of vernier caliper gages – Caliper height-gages – Gear-tooth vernier calipers – Vernier depth-gages	
MICROMETERS	19
Operating principles and mechanism – The precision of micrometer readings – Micrometers for outside measurements – Micrometers for inside measurements – Special micrometer instruments	
3. FIXED GAGES	27
CLASSIFICATION AND ADVANTAGES OF FIXED GAGES	27
MASTER GAGES	30
THE PRINCIPLES OF LIMIT GAGE MEASUREMENTS	31
LIMIT GAGES FOR LENGTH DIMENSIONS	32
External measurements—Adjustable limit snap gages – Adjustable length gages – Internal measurements—Adjustable limit plug gages	
CYLINDRICAL LIMIT GAGES	34
Cylindrical limit plug gages – Cylindrical limit ring gages	
FIXED GAGES FOR MULTIPLE DIMENSIONS	35
Purpose and operation – Thread limit gages – Taper plug and ring gages – Spline plug and ring gages	
CONSTRUCTION AND DIMENSIONING OF FIXED GAGES	40
The design of fixed gages – The material of fixed gages – The gage-maker tolerances – Wear allowance for limit gages – Allocation of gage-maker tolerances	
4. GAGE BLOCKS	44

<i>Chapter</i>	<i>Page</i>
GENERAL ASPECTS .	44
The need for dimensional reference standards – The development of gage blocks – Major requirements for gage blocks	
DESCRIPTION AND TECHNICAL REQUIREMENTS .	45
Boundary dimensions – Gage-block length–The functional dimension – Geometry of form – Surface condition – Non-dimensional characteristics	
THE MATERIAL OF GAGE BLOCKS .	48
The coefficients of thermal expansion of gage-block materials	
THE MANUFACTURE OF GAGE BLOCKS	49
Reclamation of worn gage blocks	
GAGE-BLOCK SETS AND ACCESSORIES – THE HANDLING OF GAGE BLOCKS .	53
The composition of gage-block sets – The handling of gage blocks – Gage-block accessories – The accuracy of gage-block accessories – Wear blocks	
APPLICATIONS FOR GAGE BLOCKS .	54
Applications for grades "AAA" and "A" gage blocks – Applications for grades "A+" and "A" gage blocks – Applications for grade "B" gage blocks	
CALIBRATION OF GAGE BLOCKS .	57
Impairment of gage-block accuracy – Periodic calibration of gage blocks – Inspection of gage blocks for calibration – Comparator measurement of gage-block lengths – Length interference measurement of gage blocks – Certification of calibration – Utilization of calibration results	
SPECIAL PURPOSE END STANDARDS .	61
5. COMPARATIVE LENGTH MEASUREMENTS WITH MECHANICAL INDICATORS	63
GENERAL EVALUATION OF THE MEASURING SYSTEM AND OF THE INSTRUMENTS .	63
The principles of comparative length measurement – Major applications of indicator instruments – Advantages of mechanical indicators – Systems of mechanical amplification	
DIAL INDICATORS .	68
Definition of the category – Advantages and limitations of dial indicators – The American Gage Design – Specifications for dial indicators – The accuracy of dial indicators – Dial indicator components, accessories and attachments	
TEST TYPE INDICATORS .	77
Basic Design – Cosine error in test indicator measurements – Test indicator applications	
INDICATOR GAGES .	78
The general function of indicator gages – Adjustable indicator snap gages – Depth indicator gages – Shallow diameter gages – Bench comparator gages – Plate gages	
INTERNAL INDICATOR GAGES .	85
Comparative measurement of internal dimensions – System of internal indicator measurement – Examples of internal indicator gages – Internal groove indicator gage with parallel jaw movement – Internal groove indicator gage in swing-arm design – Concentricity and bore location indicator gages – Setting of bore indicator gages	

<i>Chapter,</i>		<i>Page</i>
	HIGH SENSITIVITY MECHANICAL INDICATORS .	95
	General characteristics – Sector type precision indicators – High sensitivity indicator gages – Precision indicators with twisted-strip type mechanism – Floating lever indicators – The Sigmatic gages	
	MECHANICAL INDICATORS WITH ELECTRICAL LIMIT-POSITION SIGNALING .	98
	OPTICALLY ASSISTED MECHANICAL COMPARATORS .	99
	The Sheffield visual gage – Tilting-mirror type optical comparators	
6.	PNEUMATIC GAGING	103
	OPERATING PRINCIPLES AND GAGE SYSTEMS	103
	General definition – The operational systems – The applicational advantages	
	PRINCIPAL ELEMENTS AND OPERATION OF PNEUMATIC GAGING SYSTEMS	108
	The speed of response in pneumatic gaging – Zero setting and amplification adjustment – Adjustable, variable and constant amplification	
	THE PNEUMATIC CONTROL UNITS	110
	Flow type pneumatic gaging systems – Velocity differential type air gages – Pneumatic gages with air pressure controlled by water chamber – Pressure type air gages with fixed amplification – Pressure type air gages with variable amplification – Differentially-controlled constant-amplification air gages	
	THE SENSING MEMBERS OF AIR GAGES	116
	Operating fundamentals of sensing in pneumatic gaging – Basic types of air-gage sensing members – Design principles of direct sensing air-gage heads – Contact type sensing-members of air gages	
	APPLICATIONS FOR PNEUMATIC GAGING	123
	Pneumatic measurement of interrelated dimensions – Diverse non-basic applications for pneumatic gaging	
7.	ELECTRONIC GAGES	129
	BASIC CHARACTERISTICS AND APPLICATION ADVANTAGES	129
	The principles of dimensional measurement with electronic gages – Application advantages of electronic gages	
	OPERATIONAL SYSTEMS AND PRINCIPAL ELEMENTS	130
	ELECTRONIC COMPARATOR GAGES	135
	Electronic gage block comparators – Differential gaging of linear dimensions	
	ELECTRONIC INSTRUMENTS IN HEIGHT GAGE APPLICATIONS	142
	Diverse applications for the electronic test indicator	
	ELECTRONIC COMPARATOR GAGES FOR INTERNAL MEASUREMENTS	143
	Two-point contact, internal comparator gages – The setting of internal comparator gages – Single-point contact, internal comparator gage	
	DIVERSE APPLICATIONS OF ELECTRONIC GAGES	150
	Rotatable sensing heads for electronic gages – Digital readout systems – Numerical recording systems – Recording discrete length dimensions on a strip chart	

<i>Chapter</i>		<i>Page</i>
8.	ENGINEERING MICROSCOPES	155
	Functions of engineering microscopes – General operational procedure	
	THE OPTICAL OBSERVATION SYSTEM OF ENGINEERING MICROSCOPES	156
	Optical system with intermediate image – Supplementary optical equipment – Referencing for distance measurements	
	THE STAGING AND DISPLACEMENT MEASURING MEMBERS	158
	LENGTH MEASUREMENTS WITH THE MICROSCOPE	160
	Referencing by graticule cross hairs – Referencing by optically-indicating mechanical contact – Referencing by grazing-incidence light beam – Referencing by double-image sighting	
	GONIOMETRIC MEASUREMENTS WITH THE MICROSCOPE	171
	Optical protractors – Optical rotary table	
	INSPECTION BY CONTOUR FORM COMPARISON	176
	SURVEY OF ENGINEERING MICROSCOPES	178
	Centering microscopes – Machine-tool microscopes – Plain coordinate measuring microscopes – Toolmaker microscopes – Measuring microscopes	
9.	OPTICAL PROJECTORS	187
	THE OPERATING PRINCIPLES OF OPTICAL PROJECTORS	188
	THE PRINCIPAL ELEMENTS OF OPTICAL PROJECTORS	191
	General arrangement – Instrument table for work staging and positioning – The optical system–Magnifications – The projector screen – Staging and measuring capacity	
	COMPLEMENTARY EQUIPMENT OF OPTICAL PROJECTORS	196
	Optional projector equipment – Object staging fixtures – Accessories for screen-image analysis	
	APPLICATIONS OF OPTICAL PROJECTORS	201
	Projected and reflected object image	
	APPRAISAL OF OPTICAL PROJECTOR CHARACTERISTICS	206
10.	ANGLE MEASUREMENTS	211
	UNITS OF ANGLE MEASUREMENT	211
	GEOMETRIC CONDITIONS MEASURED IN ANGULAR UNITS	211
	SURVEY OF ANGLE-MEASURING SYSTEMS AND TECHNIQUES	215
	ANGLE MEASUREMENTS BY COMPARISON TO ANGULAR REFERENCE BODIES	215
	Fixed type, angular reference bodies – Fixed taper gages – Angle gage blocks – Adjustable angular reference bodies – Measurement of cone-shaped technical parts by comparison to a virtual body, or by attributes	
	ANGLE MEASUREMENTS WITH DIRECTLY-INDICATING INSTRUMENTS	227
	Direct angle measurement by mechanical contact – Direct angle measurement by optical alignment	

	MEASUREMENT OF ANGULAR SPACINGS BY CIRCULAR DIVISION .	229
	Systems of instruments for controlled rotational movement – Description of characteristic dividing instruments – Indexing tables with meshing radial serrations – Rotary tables with continuous rotational positioning by precision worm – Optical dividing heads and rotary tables – Calibration of circular dividing instruments	
	THE MEASUREMENT OF INCLINES .	239
	Spirit levels – Electronic levels – Clinometers	
11.	THE MEASUREMENT OF STRAIGHTNESS, FLATNESS AND PERPENDICULARITY	243
	Optical tooling	
	STRAIGHTNESS AND ALIGNMENT MEASUREMENTS .	246
	The alignment telescope – Jig transits – Optical levels – The engineering theodolite – Auxiliary equipment for optical tooling	
	THE MEASUREMENT OF FLATNESS .	257
	Toolmaker flats – Optical flats – Surface plates – The inspection of surface plates for flatness	
	MEASUREMENT OF PERPENDICULARITY .	266
	Mechanical means of squareness inspection	
	THE SYSTEMS AND APPLICATIONS OF AUTOCOLLIMATORS .	269
	Barrel type autocollimators – Folded-beam type autocollimators – Comparison autocollimator – Photoelectric autocollimators – Automatic position-sensing autocollimator – Autocollimator with continuous servo setting – The optical square (pentaprism)	
12.	THE SYSTEMS AND APPLICATIONS OF MEASURING MACHINES .	283
	DEFINITION AND GENERAL EVALUATION .	283
	SINGLE-AXIS MEASURING MACHINES .	285
	Optical length-measuring machines in vertical arrangement – Mechanical length-measuring machines in horizontal arrangement – Optical length-measuring machines in horizontal arrangement – The Zeiss-Jena length-measuring machine	
	COORDINATE MEASURING MACHINES .	292
	Displacement measuring devices using diffraction gratings – The Inductosyn	
	JIG-BORER TYPE MEASURING MACHINES .	298
	OPTICAL MEASURING MACHINES .	306
13.	PROFILE MEASUREMENTS .	308
	PROFILE TRACING .	309
	The systems and design of profile-tracing instruments – Advantages of systems using traversing work stage – Advantages of systems using traversing sensors – The sensing head and its stylus	
	THE VERIFICATION AND CALIBRATION OF PROFILE-TRACING INSTRUMENTS .	318
	Applications of the Profile Tracing Process – Dimensional measurements of technical parts with profile tracing	
	PROCESS TECHNIQUES OF PROFILE TRACING .	325

	RECORDER CHARTS AND THE INTERPRETATION OF CHART TRACINGS	330
14.	THE MEASUREMENT OF ROUNDNESS AND CIRCULAR CONTOURS	336
	THE CONCEPT OF ROUNDNESS	336
	CHARACTERISTIC FORMS OF ROUNDNESS DEFICIENCY	336
	THE FUNCTIONAL NEED FOR ROUNDNESS	342
	Cylindricity and coaxial roundness of interrelated surfaces	
	THE DIFFERENT SYSTEMS OF ROUNDNESS MEASUREMENT	342
	Advantages of the intrinsic datum roundness-measuring systems – Advantages of the extrinsic datum roundness-measuring systems	
	ROUNDNESS MEASUREMENTS BY REFERENCING FROM THE SURFACE OF THE OBJECT	344
	Diametrical measurements of roundness – Roundness inspection by referencing from V-block-supported surface elements – Roundness measurements between centers	
	ROUNDNESS MEASUREMENTS BY COMPARISON TO A REFERENCE CIRCLE–THE CIRCULAR TRACING PROCESS	351
	The operating principles of the circular tracing process – Comparative evaluation of the two basic systems of circular tracing instruments – The application potentials of the circular tracing process – The assessment of roundness condition	
	THE INSTRUMENTS AND TECHNOLOGY OF ROUNDNESS MEASUREMENT BY CIRCULAR TRACING	357
	Roundness measuring machines–Characteristics of representative models – Circular arc curvature measurements – Recorder charts–Appraisal of various types and characteristics – The staging of specimens – The stylus of roundness-measuring instruments – The frequency response of roundness-measuring instruments	
	THE ASSESSMENT OF ROUNDNESS TRACINGS	364
	Distortions in the graphic representation of the roundness conditions – The verification of roundness-measuring machine performance	
15.	SURFACE-TEXTURE MEASUREMENTS	367
	DEFINITION OF CONCEPTS AND TERMS	372
	THE METHODS OF SURFACE-TEXTURE MEASUREMENT	373
	SURFACE-TEXTURE MEASUREMENT WITH STYLUS TYPE INSTRUMENTS	377
	Elements of stylus type surface-roughness measuring instruments – Calibration of stylus type, average-roughness measuring instruments	
	REPRESENTATIVE MODELS OF STYLUS TYPE SURFACE-TEXTURE MEASURING INSTRUMENTS	384
	Instruments with hand-held pickup heads – Average indicating instrument with interchangeable pickups and drive units – Surface analyzing instrument with recorder for multiple characteristics – Integrated averaging and profile-recording instrument with different datum accessories	
	THE ASSESSMENT OF SURFACE TEXTURE	390
	With stylus type instruments – By area sampling – Sensory assessment of surface texture – Surface-texture examination by light interference	