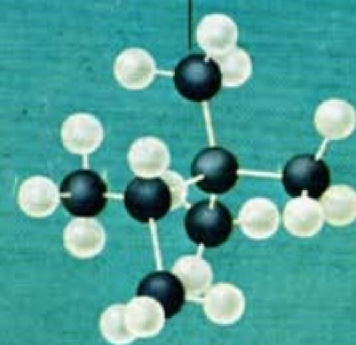
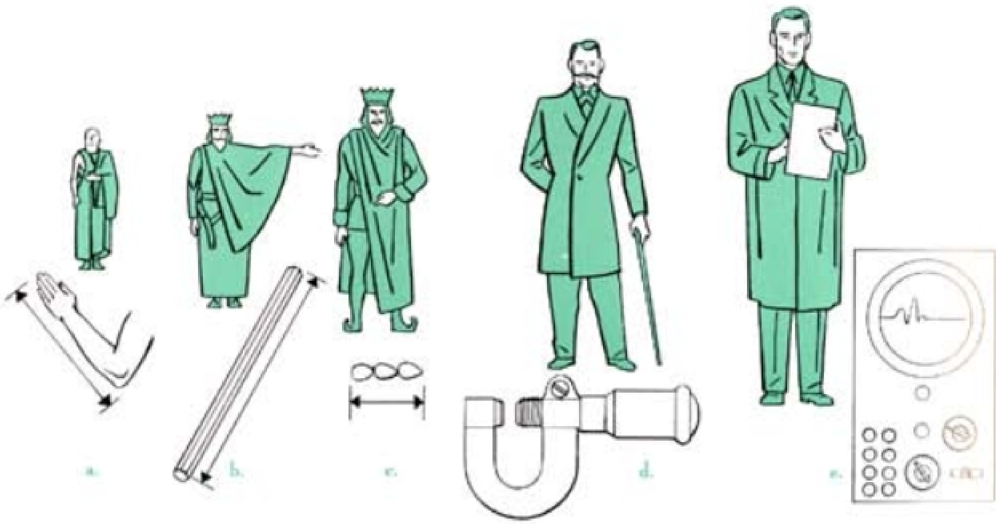
PRECISION

A Measure of Progress . . .





a. *Cubit,* one of the earliest forms of measurement.

b. *The Iron Ulna,* one of the first standards.

c. *Barleycorns,* an early standard that was universally available.

d. *Micrometer,* the first precision measuring instrument.

e. *Oscilloscope,* one of the many modern high-precision measuring instruments.

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A Measure of Progress

Public Relations Staff

GENERAL MOTORS

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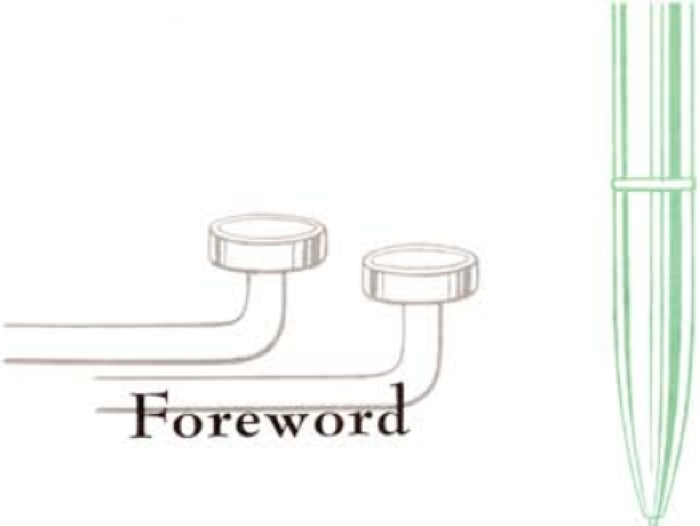
Thirteenth Printing



Foreword

NEARLY every American home has a measuring stick of one kind or another. It may be a 12-inch ruler down on Dad's workbench, a tape measure in Mom's sewing basket, or the familiar wooden yardstick buried away somewhere in a closet.

Whenever Grandma comes for a visit, one of them is resurrected from its hiding place, and Junior is backed stiffly against the wall to see how much taller he has grown.

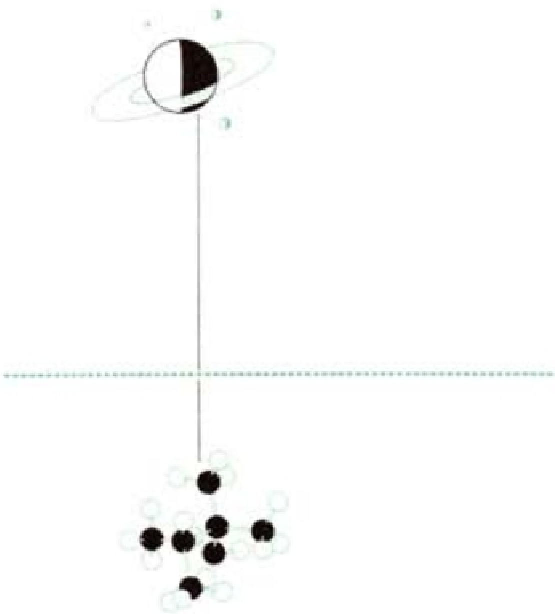
"My goodness—he's 4 feet, 3 inches . . . *and a little over*!"

How much over? Well-l-l—it's not important because Junior is growing like a weed and by next week he'll be a different height anyway. (Besides, to be frank about it, some of us have forgotten what all those little marks between the inch lines stand for.)

After all, for most household measurements, a "little over" or a "little under" is close enough for practical purposes. Consequently, we aren't too concerned about reading the dimension within a cat's whisker one way or the other.

However, in mass-production industries, where things are made by the millions, measurements have to be on the nose. Rulers and yardsticks were all right for the horse and buggy days, but now many dimensions have to be accurate within thousandths of an inch, and sometimes even millionths. Why? Because mass production is based on interchangeability, which, in turn, demands that everything fit together just right. The only bridge between the engineers who design things and the men who make them, is the blueprint which contains the dimensions. Only when specifications are followed exactly out in the factory can assembly lines run smoothly. Precision is the handmaiden to engineering and the keystone to our high standard of living!

In this booklet, we hope to show you how incredible accuracy is achieved. We'll by-pass all the technicalities, and show you how the inch, and foot, and yard came into being. We also think you'll be interested in learning how the classic old measuring devices . . . like the ruler, caliper, and even micrometer . . . have already been outmoded by new, more precise scientific instruments and techniques.



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Rule of the Thumb

NOAH must have been a good carpenter. The Ark he built stayed afloat more than 120 days during one of the heaviest rainstorms and worst floods ever recorded in history.

But Noah doesn't deserve all the credit. He was told how big to build his boat . . . it was to be 300 cubits long, 50 cubits wide, and 30 cubits high.

Even today, we would consider that a fairly good-sized ship. A cubit was roughly 18 inches long. That meant Noah's 300 cubit floating menagerie was about 450 feet from stem to stern.

Of course, the Ark had to be big to house all the animals it was expected to carry. But size alone was not the only thing that made the job outstanding. Noah managed to build his Ark according to instructions without the aid of a "yardstick"!

In Noah's day though, the lack of a yardstick was not a serious drawback. For one thing, the yardstick hadn't been invented yet . . . the world had to wait several thousand years more for that. Besides, the ancients did have a rather crude way of measuring things, and, while it was far from accurate, it usually was good enough for most practical purposes. So long as only one craftsman was doing the measuring, and so long as he completed one job at a time rather than try to make a number of articles piecemeal to be assembled later, it didn't make much difference how accurate their yardsticks were or even how long they were.

As a matter of fact, even now it doesn't make much difference how long a mile or a yard or an inch is, or how heavy a pound or an ounce is. What really is important is that everyone means the same thing when they specify an inch, or a foot, or a ton, or a quart. In other words, a measurement has to be *standard* so that it means the same thing to everyone.

Actually, the cubit of Noah's time was the length of a man's forearm. It was the distance from the tip of his elbow to the end of his middle finger. In some respects, this was a mighty handy measuring stick. It always was readily available and it couldn't be mislaid, so nobody had to waste time rummaging around trying to find it. Also, it was reasonably convenient to use, and everyone had one.

But obviously, a cubit was not a positive fixed dimension . . . it was not *standard.* Its length would vary according to the size of the man doing the measuring. If Noah had been just a little fellow, his Ark might have measured only about 400 feet long. On the other hand, if he had been

a big hulking giant of a man, it could easily have run as much as 500 feet in length. But again, so long as Noah was the only one doing the measuring, he could be fairly certain that both sides of the Ark would be the same length and would meet at the bow and at the stern.

While we no longer use the cubit as a unit of measurement, we do have some other present-day standards that originated in about the same way. Our foot-rule started out as the length of a man's foot. However, in Noah's day, just as today, some people had bigger feet than others . . . so, in the early days of history, the foot varied in length between eleven and fourteen inches.

Once the ancients started using arms and feet for measuring distance, it was only natural that they also thought of using fingers, and hands, and legs. They also may have discovered that some surprising ratios exist in body measurements.

What we now call an inch originally was the width of a man's thumb. It also was the length of the forefinger from the tip to the first joint. Twelve times that distance was the same as a foot. Three times the length of his foot was the distance from the tip of a man's nose to the end of his outstretched arm. This distance very closely approximates what we now call the yard. In fact, many housewives still find that the easiest and quickest way to estimate the number of yards in a piece of cloth.

Two yards make a fathom which, thousands of years ago, was the distance across a man's outstretched arms. Half a yard, was the 18-inch cubit, and half a cubit was called a span. This was the distance across the hand from the tip of the thumb to the tip

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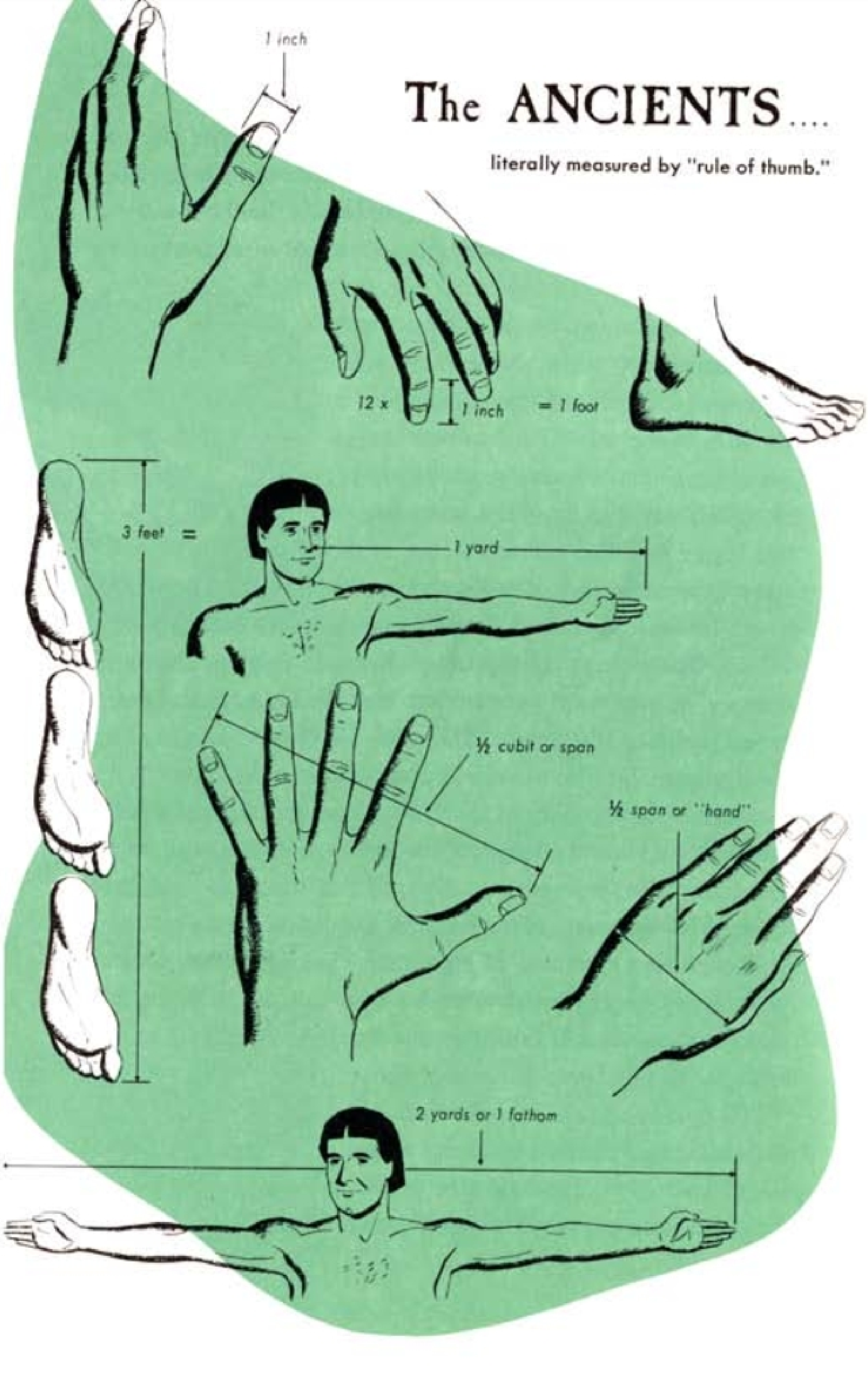
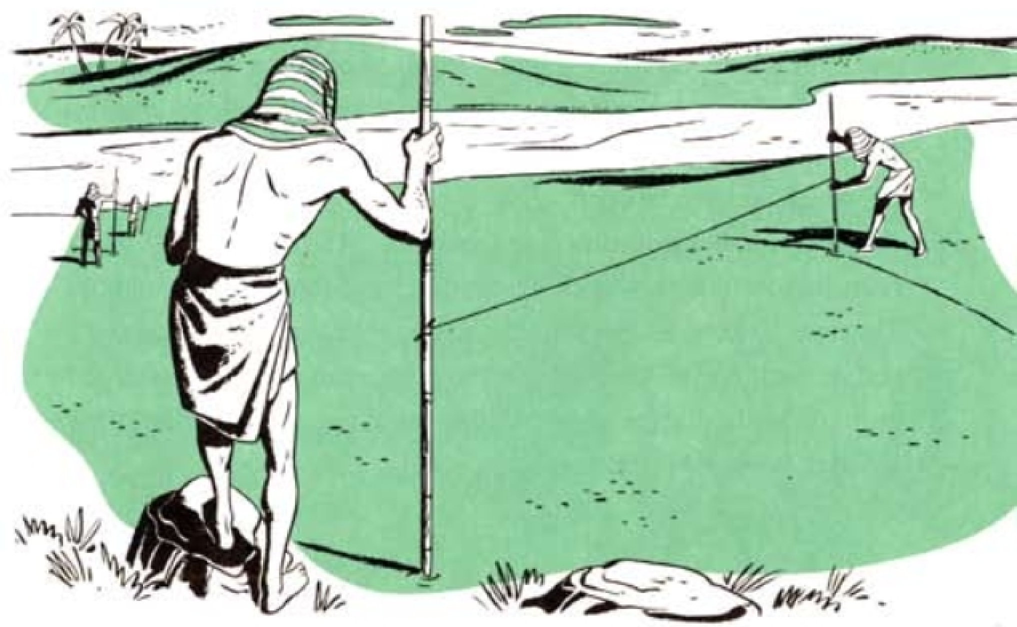
literally measured by "rule of thumb."



of the little finger when the fingers were spread out as far as possible. A hand was half a span. It used to be 4½ inches but, as it is used in England today to measure the height of horses, it is understood to be 4 inches.

For thousands of years, this was the way people measured comparatively short distances. As each succeeding civilization added its bit to mankind's knowledge, they kept building up the accumulation of measuring standards and techniques. Some contributed weight measures. Others showed us how to measure time. Still others gave us methods for surveying big areas of land and establishing boundaries.

When the Egyptians were the leading citizens of the world, they developed a clever method of measuring land. Every spring, the Nile river would overflow and destroy most of the landmarks. As the floodwaters receded, they would leave a layer of fine rich silt that made the best farm land in the world. Since the land was so valuable, naturally there were a lot of arguments about where each landowner's boundary had been before the fences and field markers were washed away.



Gradually, these Egyptian farmers developed a practical way of relocating their boundary lines each year. Two men with two sticks tied to the ends of a long rope would lay out a series of parallel and perpendicular straight lines. Starting from fixed points above flood level, they would strike arcs in the mud and establish geometrically accurate rectangles to outline each owner's field.

This system proved so successful that a Greek by the name of Euclid, who was teaching school in Alexandria, Egypt, at the time, refined these principles into that branch of mathematics which we now call Geometry. The very word geometry itself is a combination of two Greek words meaning earth measurement.

Probably about the time man first gained the concept of distance and figured out ways to measure it, he also began to wonder about weight. Most likely the prehistoric barbarians, even before their conversational level got beyond the grunt stage, knew that size had nothing to do with weight. From experience, they learned that a man had to work just as hard to carry a small stone as he did to carry a big bundle of straw. But oftentimes it was difficult to tell which was the heavier.

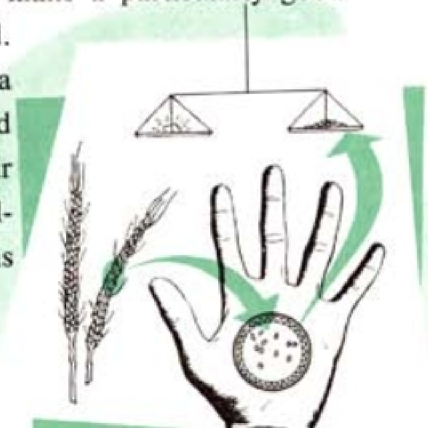
Then someone invented the balance. At first, it must have been just an ordinary stick suspended by a thong in the middle. The two objects whose weights were to be compared could be tied at each end of the stick. If the stick remained level with the ground, both objects weighed the same no matter what their differences were in size.

In this way, people could equalize weights so that there wouldn't be any disputes about who was carrying the heaviest load. But if their balance stick tilted down at one end, they couldn't tell how much heavier that object was.

It took several thousand years for people to overcome that obstacle. Then the Babylonians made an important improvement. Instead of merely comparing the weights of two objects, they compared the weight of each object with a set of stones they kept just for that purpose. In digging through the ruins of their cities, archaeologists have found some of these stones all nicely shaped and polished. These probably were the world's first weight standards.

Apparently, the Babylonians used different stones for weighing different commodities. And even in modern English history, somewhat the same basis has been used for weight measurements. For the horseman, the "stone" weight was 14 pounds. In weighing wool, the stone used to be 14 pounds but later usually was 16 pounds. For the butcher and fishmonger, the stone was 8 pounds. Today, the only legal stone weight in England is 14 pounds.

Although the Babylonians contributed a good idea in establishing weight standards, they didn't make a particularly good choice in what they used for a standard. Other civilizations though made a better choice. Both the Egyptians and the Greeks, when they were in their heyday, used a wheat seed as the smallest unit of weight. "As alike as two peas



in a pod" applied equally as well to grains of wheat, so here was a weight standard that was exceptionally uniform and accurate for the times.

Even today, throughout most of the world, the ***grain*** is used as a standard of weight. However, we no longer actually put wheat seeds in the pan of the balance scale. Rather, we arbitrarily have assigned a weight to what we call the grain . . . and it is a weight that is practically the same as that of an average grain of wheat.

The Arabs, too, established a small weight standard that we still use today. At the time of their civilization, gold and silver and precious stones very often were a part of trade or barter deals. In weighing such small valuable quantities, they used as a weight standard a small bean called a ***karob.*** This was the origin of the word ***carat*** which jewelers, the world over, still use to express the weight of gems and precious metals.

In trading between tribes and nations, many of these methods for measuring weights and distances were gradually becoming intermixed. But it remained for the Romans to spread this knowledge throughout the known world at the time. They carried it north into Europe, east into Asia, and south into Africa. In addition, the Romans also added some standards of their own.

As the Roman soldiers marched out into strange territory, they kept track of the distance they traveled by counting paces. A pace was the distance covered from the time one foot touched the ground until that same foot touched the ground again. In other words, it was the length of a double step.

From the averages established by thousands of Roman soldiers, this pace was standardized at about 5 feet. A thousand paces, or five thousand feet closely approximates our present-day mile.

Today, we consider the pace as the distance of just one normal step. Yet while the old double-step pace no longer is used, there still are to be found the old thousand-pace "mile-stone" markers left in many places throughout Europe by the marching Roman soldiers.

A Double Standard for the World

WHEN the Roman Empire finally passed into history, about six hundred years after the time of Christ, the rest of Europe also drifted into doldrums and indifference toward progress. This was the period historians call the Dark Ages. For the following six or seven hundred years, mankind generally made little progress and kept still fewer records of what little they did accomplish.

But then, out of the murkiness of the times, began to come occasional flashes of advances in the art of measuring. Sometime after the Magna Charta was signed in the Thirteenth Century, King Edward I of England took a tremendous step forward. Hitherto, men nearly always had used arms and legs and fingers to measure short distances. Of course, it was only human nature for some tradesmen to take advantage of differences in men's statures. Hence, to avoid confusion and arguments, King Edward ordered a permanent measuring stick made out of iron to serve as a master standard yard-

stick for the entire kingdom.

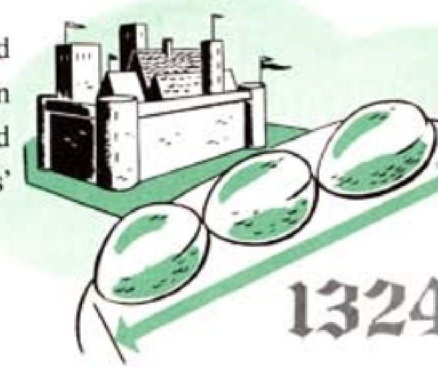
This master yardstick was called the "iron ulna." Actually, an ulna is one of the bones in a man's forearm. However, the iron ulna was standardized as the length of a yard . . . surprisingly close to the length of our present-day yard. More important though, King Edward realized that constancy and permanence were the key to any standard, therefore he had the iron ulna made of the strongest and toughest material of the day.

At the same time, King Edward also decreed that the foot measure should be one-third of the length of the yard, and the inch should be one thirty-sixth. Merchants and customers now had an invariable and impartial judge in disputes arising over length.

But having just one single master standard of length to serve a whole nation was not enough. Many people lived and traded in remote outposts of the kingdom . . . many, many days travel away from London where the iron ulna was kept. To these outlanders, the iron ulna must have been about as useless as a raincoat left hanging forgotten in the closet at home on a drizzly day. Unless they had actual access to it when they needed it, their national yardstick didn't do some of the English people much good.

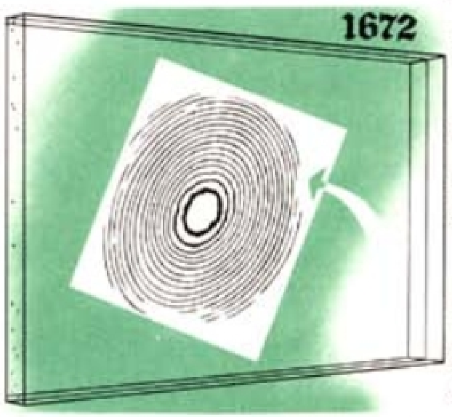
Most likely the next English monarch, King Edward II, recognized this shortcoming for, in 1324, he surprisingly enough reverted back to the seed idea of the ancients. Knowing that he would have to select some standard that was universally available, King Edward II passed a statute that "three barleycorns, round and dry," make an inch.

However, seeds as well as fingers and feet were no match for a world that soon was to emerge from the ignorance and crudities of the Dark Ages. Columbus'



voyage to the New World not only made the civilized world bigger, but it also helped broaden men's imaginations. Science and an industrial revolution soon were to make the old rule-of-the-thumb techniques of measuring hopelessly inadequate.

In 1672, Sir Isaac Newton presented the world with some new ideas on the nature of light and color. He had noticed that when two very flat pieces of glass were pressed together, he could see circular bands of rainbow-like colors. These were called Newton's Rings. Actually, Newton had within his grasp an almost incredibly precise method of measurement . . . but he didn't recognize it as such at the time. Later, other scientists were to build on Newton's groundwork and establish a new branch of science called ***interferometry***. Today, this method of using a ray of light as a yardstick enables men to measure distances within millionths of an inch . . . but we'll tell you about that in a later chapter.

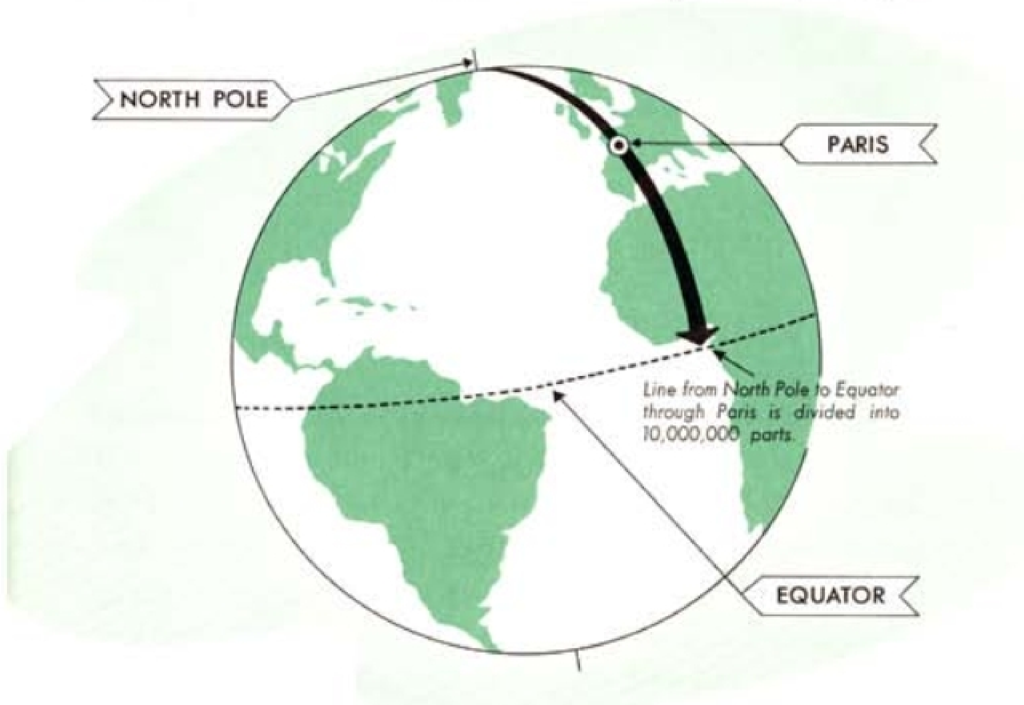


Meanwhile, as the scientists were experimenting in their laboratories, practical tradesmen were making themselves permanent standards.

In 1793, at the time Napoleon was beginning his rise to power, the French government adopted an entirely new system of standards. It was called the ***metric system*** and it was based on what they called the ***meter.*** The meter was supposed to be one ten-millionth part of the distance from the North Pole to the Equator when measured on a straight line running along the surface of the earth through Paris.

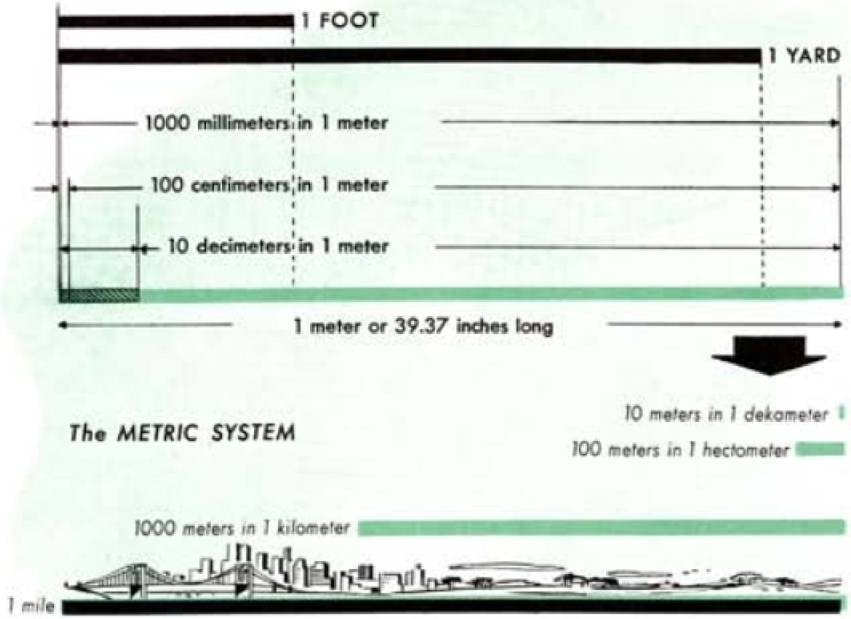
With the meter thus determined as the basis of the metric

system, other linear units of the system were set up in decimal ratios with the meter. All units are in multiples of ten. There are ten decimeters in a meter, a hundred centimeters in a meter, and a thousand millimeters in a meter. Going in the other direc-

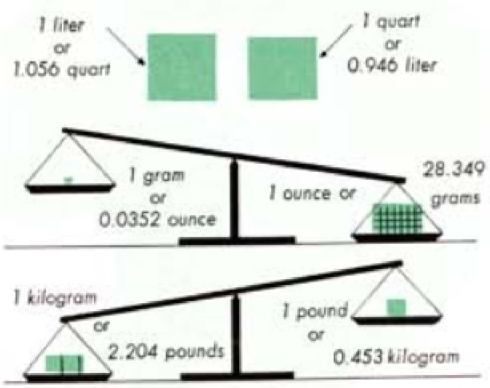


tion, there are ten meters in a dekameter, a hundred meters in a hectometer, and a thousand meters in a kilometer. Compared to our own yardstick, the meter is just a little longer . . . it is 39.37 inches long.

The metric system also has volume and weight measures. The ***liter*** is the basic measure of volume. It corresponds roughly to our quart. For weight, the basic unit in the metric system is the gram. This is a very small unit, for it takes a thousand grams—or what is known as a kilogram—to balance with a little less than 2¼ English pounds.



In tying the metric system to what were considered the permanent unchanging dimensions of our globe, and in making the various units in convenient multiples of ten, the French government naturally thought it had a scientific foolproof system of weights and measures that would be easy to use and would be welcomed by everyone. But, like so many other theoretical planners, they found that human nature sometimes reacts a little disappointingly to even the best of intentions . . . especially when such plans tend to upset the familiar and proven habits of centuries.



In France, just as in other countries of Europe, people were accustomed to thinking in terms of yards and inches and pounds and quarts. To be sure, they had their own French equivalents for such words.

Nevertheless, when a French peasant would brag about his new wheat being a foot high already, he actually used the French word "pied". . . yet every one of his neighbors knew exactly what he meant. What's more, they were so accustomed to visualizing the length of a foot in their mind's eye, that if the braggart had been inclined to exaggerate a little, his neighbors would have been most quick to point out how high a foot really was.

On the other hand, the new meter, as a measure of length, proved confusing. Most Frenchmen would think in the old familiar terms and would have to do some mental arithmetic along with considerable head-scratching and finger-counting to convert the one quantity into another. It was like sending an American youngster out with a couple of shillings and a "tu 'pence" to buy a dime's worth of gum drops, an ice cream cone, and a stick of bubble gum . . ."and don't forget to bring home the right change!"

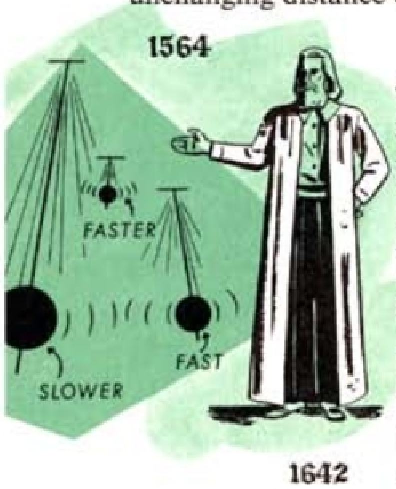
Obviously, while the metric system was theoretically sound, it just didn't fit in with the customs and traditions of the people. After nineteen years, during which most of the French people still persisted in clinging to their old familiar weights and measures, Napoleon finally had to renounce the metric system.

However, in 1837, France again went back to the meter, this time to stay. She hoped to make it universal throughout the world and, in part, was successful. Today, much of Europe and South America uses the metric system. United States though, as well as Britain and its Dominions, uses the foot and pound system.

While France was evolving the metric system, England also was setting up a more scientifically accurate determination of the yard. Where the French relied on the assumed constancy of the earth's size as a basis for the permanency of their standards, the

British turned to the measured beat of the pendulum.

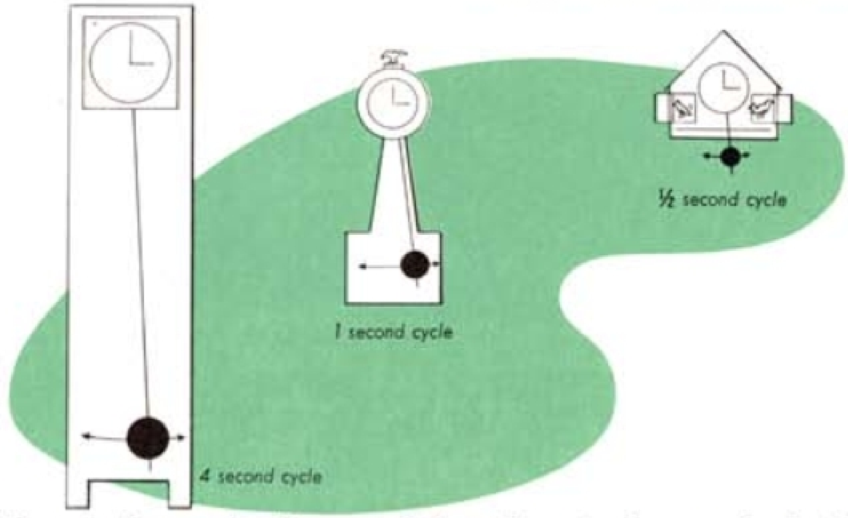
Galileo already had learned the secrets of a pendulum. He found that the length of time it took for a pendulum to complete a swing depended upon the length of the pendulum itself. The longer the pendulum, the slower it swung. He also found that a pendulum a little over 39 inches long would swing through its arc in exactly one second. Since a pendulum always behaves exactly the same way under the same conditions, here was another unchanging distance upon which to base a standard measurement.



In 1824, the English Parliament legalized a new standard yard which had been made in 1760. It was a brass bar containing a gold button near each end. A dot was engraved in each of these two buttons. These two dots were spaced exactly 1 yard apart. The same act that legalized this bar as the standard for England also made the provision that, in the event it was lost or destroyed, it should be replaced using the pendulum method to determine its length.

The two leading world powers now had exact standards for lengths, weights and volumes. A few years later, copies of both the English yard and the French meter standards were brought to this country. The English system of measuring has been almost universally adopted here although it is the metric system that actually is legalized by our government. Today, these prototype standards are carefully preserved in deep vaults in Washington, London and Paris.

In the timetable of history, events literally were right on schedule and destined to make perfect connections. After traveling



through thousands of years of time, the art of measuring had gone through innumerable stages of development and refinement. And now, at this point in our story, it had become a full-fledged science whose stature and importance were fully recognized by major governments. This transition, in which the techniques of measurement grew from an art into a science, came just in time . . . for the Industrial Age was soon to open and it was destined to remake the world.

Splitting Hairs

Most of us usually think of the Industrial Age as the era in which machines began taking over most of the labor formerly done by human hands. As far as it goes, that impression is correct . . . but that is only what appears on the surface. If it weren't for accurate measurements, there could no more be an Industrial Age, or machines, or mass production than there could be a modern motor car without the wheel.

Prior to the dawn of the Industrial Age, there were pitifully few manufactured articles available in the market place. There was a dearth of even simple necessities such as matches, nails, shoes, pencils, or even plows . . . to say nothing of watches, automobiles, radios, cigarette lighters, refrigerators, or lawn-mowers.

What few articles were available generally were handmade by highly skilled craftsmen. It was only through their inborn talent and artistry that some people were able to make things free hand so to speak . . . without the help of careful measurements.

But then, as now, there were only a few people so gifted. With talented craftsmen so rare, obviously they couldn't produce enough to supply the needs and desires of all potential customers.

Consequently there weren't enough goods to go around and prices were correspondingly high.

In the whole realm of England, for example, there probably weren't more than half a dozen cobblers who were capable of making shoes fit for a king. To be sure, common people had worn foot coverings of a sort for centuries, but they could be called shoes through courtesy only.

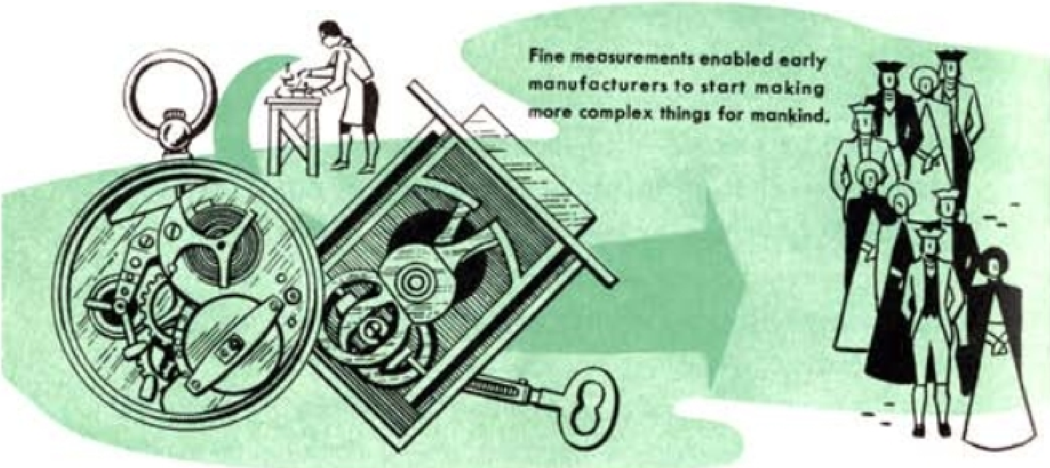
Actually, in the olden days, the so-called shoes were nothing more than sandals held on with thongs, or sabots which were crudely carved wooden clogs, or ill-fitting boots that had stiff soles with loose baggy fabric uppers. Cobblers made no attempt whatsoever to make shoes that would fit the foot of the wearer except for the very rich in what was known as the "bespoken" trade. The average man's clod-hoppers fitted very sloppily.

However, for kings and those lucky few who could afford custom-made articles, cobblers would tailor the customer's shoe to his own foot, actually using the foot as the last.

Of course, only a few of the finest craftsmen in the trade could instinctively shape a shoe that would conform to all the dimensions of the royal foot. It was a tedious task that took as much time as posing for a portrait. And the king would have to sit for irksome hours while some lowly workman fashioned him a pair of shoes, trying them on every so often as the work progressed to make sure they would fit.

But when people learned how to measure accurately, they found that dimensions could take the place of artistry. Even unskilled workers could easily be taught to cut and sew to simple inflexible dimensions. The average worker could quickly learn to make a shoe to the same length as a measuring stick, whereas he might never acquire the talent to fit it to a customer's foot.

Here was something really important in man's progress. The average person now had a better chance to make things other people were willing to buy. This meant that untrained workers had opened up for them many, many new opportunities to earn



a living. What's more, with more people making shoes, there were more shoes available for sale in the markets, so the customers were better off too. Both the maker and the user gained when accurate measurements made it possible for the average workman to duplicate the handicraft of the artisan.

All this came about in the manufacture of other articles as well as shoes. And it wasn't until after people started making things in quantity that machines really became useful. In fact, the machines themselves couldn't have been made without accurate measurements.

Once machines came into general use, the Industrial Age

spawned many little factories, mills and workshops. Each one of these new little manufacturing companies soon found that, to maintain uniform quality, they had to have accurate measuring standards for their own use.

To meet this need, each company made its own measuring sticks based on the length of the master standard yard. Oftentimes these measuring sticks were round dowels of wood tipped on each end with steel like the head of an arrow. These were called ***gauges,*** and they were much more convenient than a graduated ruler for unskilled workers to use.

It wasn't long before the companies who were making cannon balls, for example, found that they had to have gauges that were exactly the same size as the gauges used by the workers who bored out the cannon barrels. If the cannon balls were too small, the forces of explosion would leak past wastefully . . . and the cannon ball would travel only a disappointingly short distance. Of course, the cannon ball couldn't be too big either, or it wouldn't fit into the cannon barrel. From experience, the workmen learned

that both the cannon ball and the barrel had to be made to very accurate dimensions so that they would fit together with just exactly the right degree of snugness . . . a hairsbreadth either way would spoil the performance of the gun.

The same thing held true in the new-fangled steam engines that some experimenters were beginning to putter with in those days. If the piston fitted too loosely, most of the steam would escape between the piston and the cylinder, and the engine wouldn't develop enough power to do any work. On the other hand, if the piston fitted too tightly, too much power was wasted in friction and the engine wore out too fast.

James Watt, when he was building one of his first steam engines, learned the importance of accuracy. Indeed, he had considerable trouble locating a machinist who could bore out a cylinder that would be round enough and just the right size so that "a well-worn shilling would barely slip between the piston and the cylinder wall at any point."

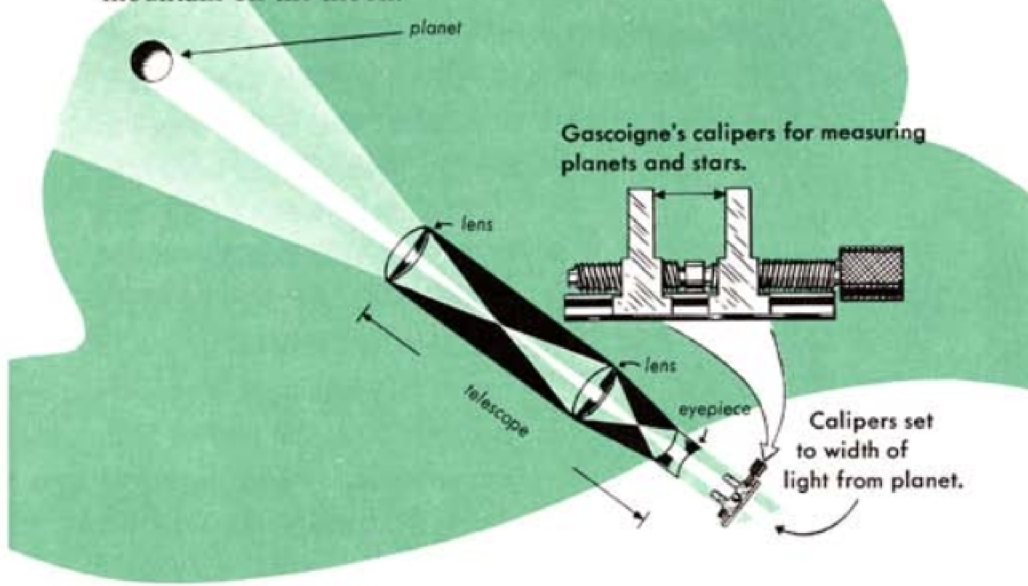
It was the same in the clock-making industry that was just getting started. It was soon found that accuracy in manufacturing had a lot to do with whether a clock would keep good time, or whether it would even run at all.

People who made things were becoming "accuracy conscious." Where they once thought in terms of the size of a barleycorn, they were beginning to talk of measurements as fine as a human hair.

Then, in 1638, an astronomer by the name of William Gascoigne showed the world literally how to split hairs. He was interested in measuring the size of the sun, and moon, and various stars. To do this, he rigged up a pair of vertical indicators in his telescope. They could be adjusted like the clamps on a child's roller skate.

By turning this screw thread, Gascoigne could move the indicators nearer together or farther apart until they just enclosed the image of the planet he saw in the lens. Then he would measure the distance between the indicators and combine it with a mathematical formula to figure out the diameter of the planet.

Of course, such measurements had to be extremely accurate. The slightest error would be magnified a million-fold in the final answer. Literally, a dust speck on the indicator would equal a mountain on the moon.

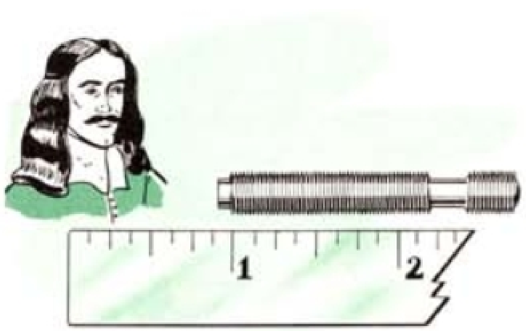


Gascoigne knew all this and he also realized that it would be humanly impossible to measure the distance between the indicators accurately enough with an ordinary ruler. In fact, no ruler could be made with scribe marks fine enough to give the degree of accuracy he required. Some other way of measuring would have to be found.

Eventually Gascoigne solved the problem by the utterly simple procedure of counting the number of times he had to turn the screw thread to open the indicators from a fully closed position. Here is how he converted that count into a dimension.

First, he laid a ruler on the screw threads and counted the number of threads in the distance of one inch. Assume for the sake of example that he counted 40. Obviously, if 40 threads occupied one inch, a single thread would represent proportionately less distance. Everyday arithmetic shows that 1 divided by 40 results in a decimal fraction of .025 (twenty-five thousandths of an inch).

Thus, Gascoigne knew that for every single turn of the screw thread, the indicators would move .025 inch. This was a higher degree of precision than could be obtained with a ruler . . . but even so, it was not the last word.

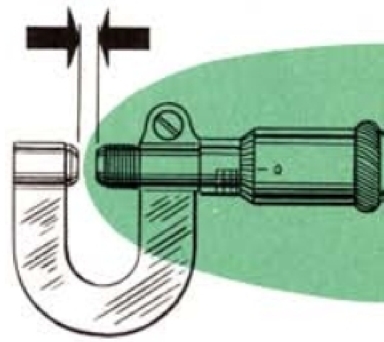


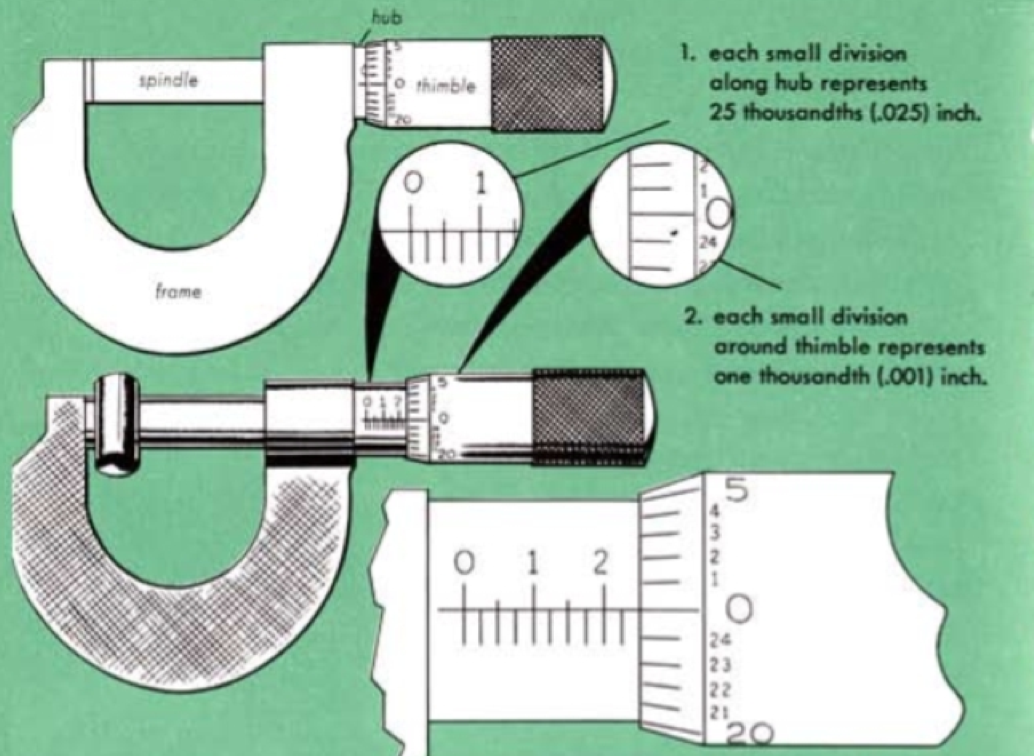
Gascoigne went further and reasoned that if each full turn of the screw thread was equal to .025 inch, a fractional part of a turn would amount to a proportionately fractional part of .025. For example, a one-fifth turn of the screw thread would move the indicators the unbelievably short distance of .005 (five thousandths of an inch)!

Few people of the day understood how small a dimension a few thousandths of an inch is. Still fewer appreciated the much more important fact that here was an entirely new way of measuring. Always before, people had determined the length of something by the simple method of comparing it *directly* with something else of known length . . . like a ruler. But now, with Gascoigne's discovery, a higher degree of precision could be achieved by

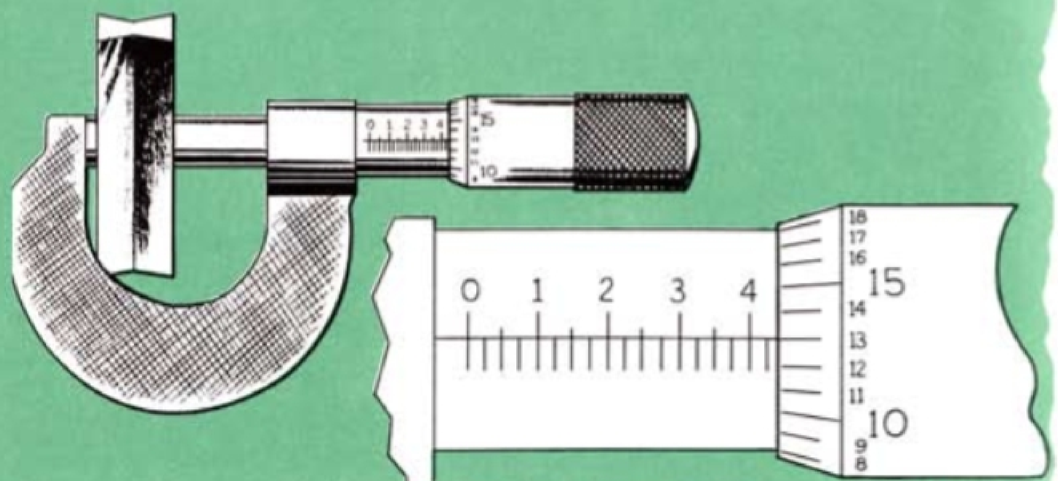
indirect means. Dimensions could be measured within a few thousandths with a combination of mathematics and a screw thread.

Several hundred years later, another Frenchman by the name of Palmer, developed the forerunner of a modern ***micrometer***. He used the screw thread idea of Gascoigne's, but he made his measuring instrument simple and easy to use by eliminating the mathematics. A series of scribed lines engraved along the hub and around the thimble made it possible to read the dimensions quickly and accurately without resorting to calculations. A few moments spent studying the illustration on the next page will show anyone how they can use a micrometer to measure within a thousandth part of an inch!





this micrometer setting is 250 thousandths (.250) inch.



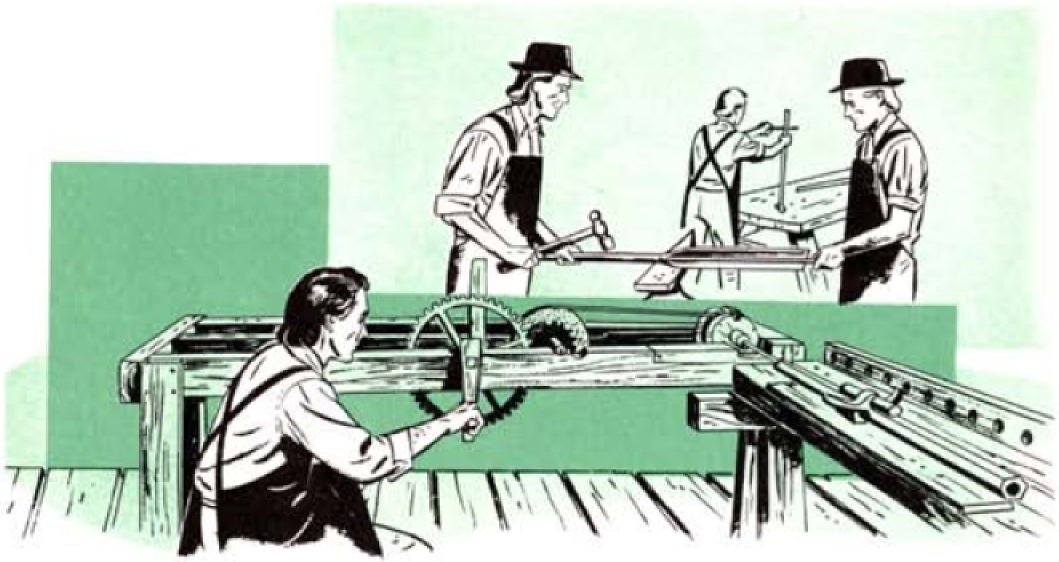
To read any micrometer setting; first, read scribe marks along hub—this one reads 425 thousandths (.425) inch. Second, read scribe marks around thimble—this one reads 13 thousandths (.013) inch. Add reading of thimble to reading of hub—.013 + .425 = .438. This micrometer is set at 438 thousandths (.438) inch.

Accuracy Fathers Abundance

FOR a good many years, precision within a thousandth of an inch gave spur to the growth of industry. This ability to measure so accurately became a two-fold blessing. It gave new talents to unskilled workers and it paved the way for mass production which, in turn, was to raise the standard of living for everyone.

Once workmen learned how to measure accurately, they soon found that they could make a number of things all alike. If each separate part was made to accurate dimensions, they all could be put together without laboriously hand fitting each individual part to its neighbor. This made for faster and better production . . . in other words, more and better things. It meant something else too. It meant that a workman could specialize in one particular operation and, in doing so, could do more and better work to earn more pay.

In boring out rifle barrels, for instance, a man no longer had to be a journeyman gunsmith. With the aid of precision gauges, an apprentice could bore out a rifle barrel just as accurately as an expert. And he could do so with only a comparatively little amount of training . . . he didn't have to spend years at beginner's wages learning the complete art of making guns. Mean-



while, other men could become specialists in making other parts of the gun . . . each worker could very soon become an expert in his particular operation.

Shortly after our Declaration of Independence, a French gunsmith by the name of Le Blanc recognized the tremendous possibilities of mass production that were made possible by accurate measurements and interchangeability. Late in the 1770's, he attempted to apply them to his business. While the idea itself was unquestionably sound, he found that other factors were very closely related to it. For one thing, such a system would require more workers, although because of the increased output, the total man-hours per gun would be less. Nevertheless, more workers would necessitate a larger management staff to coordinate the enterprise. Also, it would take a large investment to buy machines, tools, gauges, and to pay the wages.

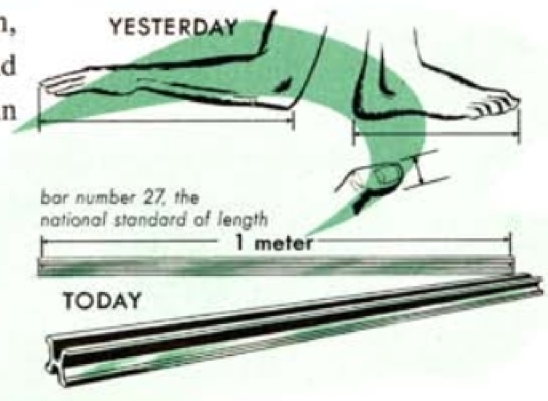
While Le Blanc could see that his plan would result in enormously greater output per man, he could not raise enough money to put his ideas to work. A few years later though, Eli Whitney proved the soundness of Le Blanc's ideas.

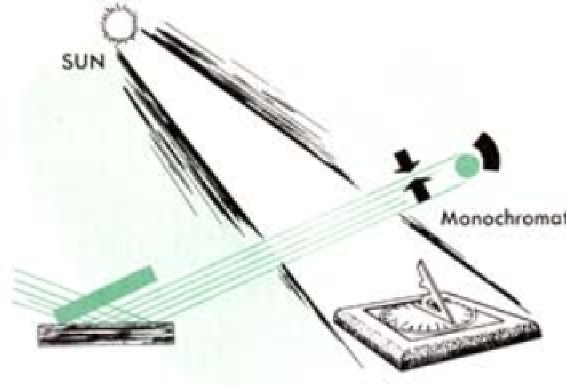
In fulfilling a contract with the United States government for a large order of rifles, Whitney fathered the art of mass production. Instead of gathering together a number of master gunsmiths, each of whom could build a complete rifle, he first had made some accurate gauges and machines. Then he trained ordinary workmen to become experts in making one particular part of the gun.

Through specialization, the workmen became so adept at their jobs and, through the use of precision gauges, they did such accurate work that the guns could be assembled immediately without any painstaking and time-consuming filing and hand fitting. With an initial investment of capital in equipment, Whitney was able to provide his workers with the tools and gauges that enabled them to match the quality of a craftsman's handiwork. And, working together under skillful co-ordination as a team, they produced infinitely more than would have been possible had they all worked individually with each man making a complete gun by himself.

Once the relationship between measurements and interchangeability and mass production was fully appreciated, the same ideas were applied to many other industries. As a result, factories began an outpouring of things people wanted.

A thousandth of an inch is so small it can hardly be seen, yet it is one of the most important things in modern living. For accuracy is the keystone to interchangeability, which in turn permits mass production, which in turn means more and better things in our American way of life.





Measuring with a Ray of Light

WHEN the Industrial Age first began, each little factory operated pretty much by itself. Gradually, however, as some products grew more and more complicated, the manufacturing job became too complex and unwieldy to handle in one shop. Consequently, some companies started specializing in the manufacture of various parts. Others processed raw materials. Still others fabricated final products out of the parts and materials made by other producers. It was similar to the division of labor in which the farmer grew the grain, the miller ground it into flour, and the baker made it into loaves of bread.

The automobile industry of today is a classic modern example of that development. No single car maker manufactures a complete vehicle by itself. Separate basic industries process raw materials into steel, rubber, textiles, paints, glass; individual specialty companies make tires, windshield wipers, nuts and bolts, light bulbs . . . the list is almost endless.

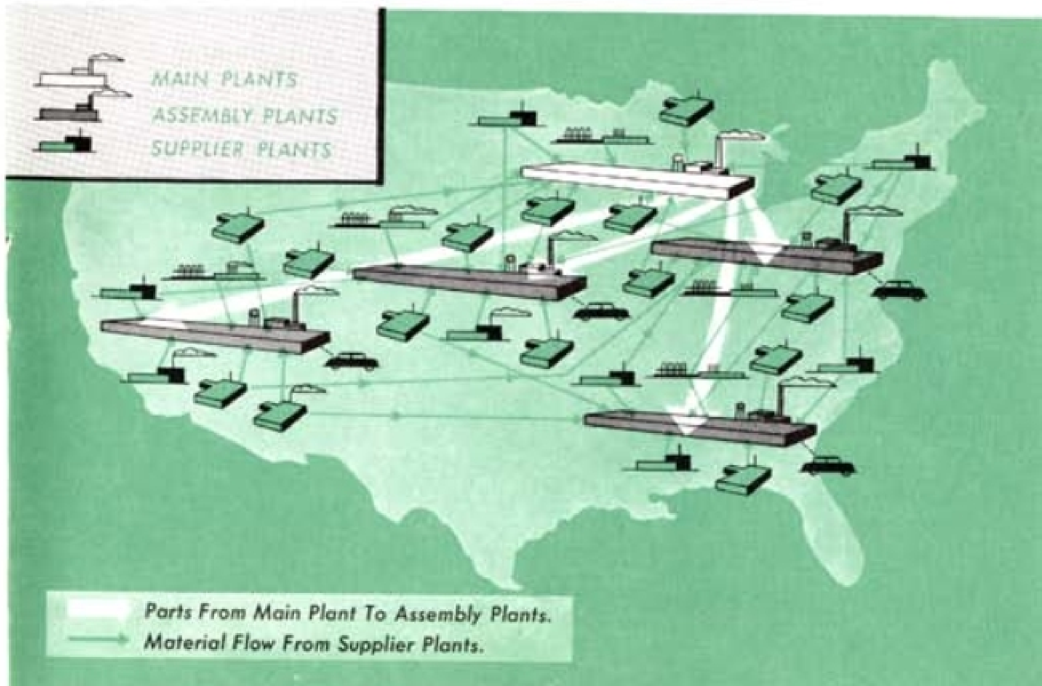
In addition to the numerous independent suppliers that furnish automotive materials and parts, the automobile company itself may have many plants scattered throughout the country. Some may make engines. Others may make bodies, axles, transmissions . . . and all the many separate units that make up a com-

plete automobile. Altogether, there may be hundreds of factories that contribute to the production of a single motor car.

The very fact that the output of all these various plants can flow into an assembly line and fit together is a triumph of the science of measuring. It means that every factory, whether large or small, must have at its convenience an accurate set of standards to which it can set its gauges.

In the early days of the Industrial Revolution, manufacturers struggled with homemade gauges and standards that seldom were a perfect match with the ones used by other manufacturers. As a result, there was much confusion and difficulty in assembling any final product when the parts were made in more than one factory.

As the Nineteenth Century drew to a close, a young workman in a Swedish rifle factory recognized the need for an extremely accurate set of standards that would be available to all manufacturers. His name was Carl Johansson, and it was his ambition to produce, for industry, standards that would be as



nearly exact as possible in comparison with the government-owned standards.

Actually, the word *exact* has no place in the science of measuring. The only measurements that can be considered to be exact are the prototype standards themselves which the governments keep stored under lock and key in deep vaults. Even so, there is a few millionths of an inch difference between the standards owned by the different governments.

Only rarely does anyone ever see these prototype standards, much less touch them. The only people who have any access to them at all are highly trained scientists.

Since these prototype standards were not available for general use, it was Carl Johansson's self-chosen career to make many sets of standards with the same degree of accuracy which could be put to practical use in industry. Eventually he succeeded in making a complete set of steel blocks with which he could measure most of the dimensions commonly encountered in manufacturing. These blocks were so carefully and painstakingly made that each one of them was accurate to within only a few millionths of an inch!

checking height gauge with "Jo" blocks.

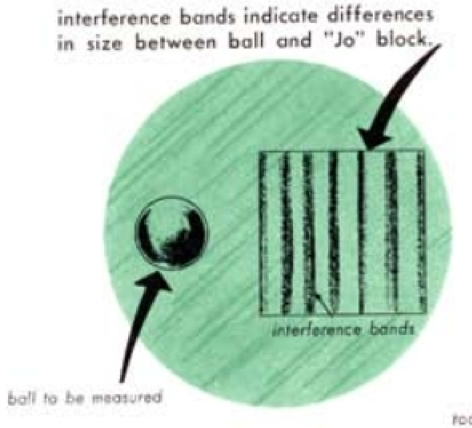
It is hard enough to picture in your mind anything as fine as even a thousandth of an inch . . . but a millionth of an inch is almost beyond imagination. About the only way it can be grasped even vaguely is to visualize it as the distance a railroad rail would sag if a fly landed on it.

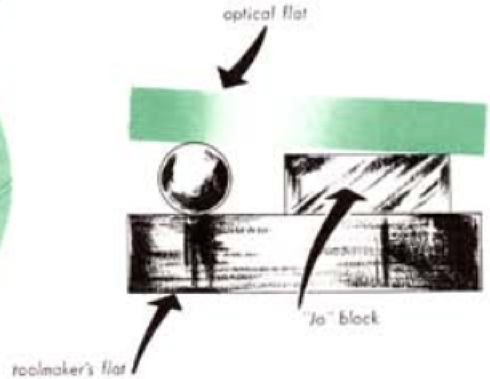
Once Johansson learned the techniques of making his ultra-precise measuring blocks, he began to produce complete sets of them in quantities. These were sold to industries all over the world, but principally in the United States and the more industrial nations of Europe.

In most cases, these gauge blocks were not used directly for measuring at the machine. Rather, they were, and still are, used in factories as master standards to which all other gauges are set. Very often, even in this role, they are used in an indirect way.

Most of the time, Johansson gauge blocks are used along with a flat disc of glass which is about six inches in diameter. It is called an ***optical flat.***

In actual measuring practice, the optical flat is laid across both the Johansson gauge block and the production gauge being checked. When a special filtered light is allowed to pass through the optical flat and reflect back from the upper surface of the Johansson gauge block, alternate bands of light and dark oftentimes are seen. This is an indication that the Johansson gauge block and the production gauge are not the same size. A trained technician can analyze these bands and tell within a few millionths of an inch how much higher one gauge is than the other. Here, briefly, is how it works.



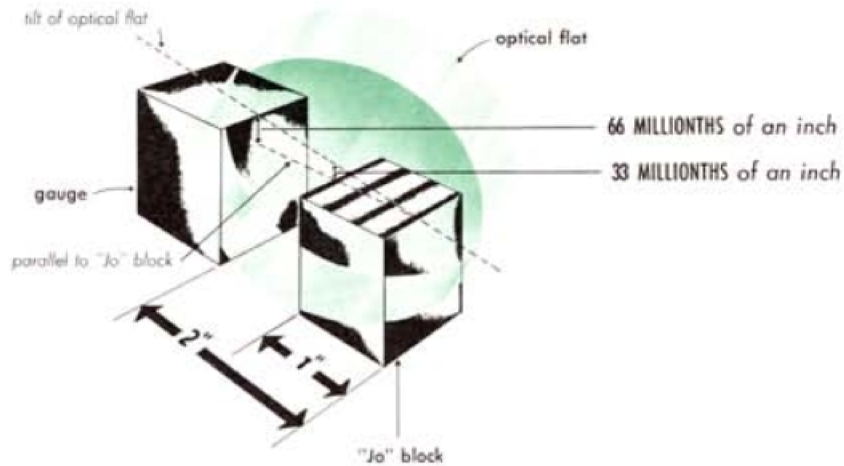


All light rays are considered to be wavelike in form, much the same as the waves on the surface of water. We've all seen how water waves behave. When they roll in from the open sea and strike against a seawall, they surge back and meet the next incoming wave. As the two waves join, they double in size and leap high into the air. If you've ever noticed closely, the point in front of the seawall where they meet and leap high is always some distance that is proportionate to the distance between the incoming wave crests.

The same thing happens with light waves. When the two gauges are not exactly the same size, the optical flat lying across them is tilted ever so slightly. This leaves a microscopically thin wedge-shaped air space between the optical flat and the Johansson gauge block. Light passing through the optical flat

reflects back from both the upper face of the "Jo" block and the bottom surface of the glass. This means that the two reflected light rays travel different distances before they rejoin. Just how they reflect and rejoin is rather complicated and comparatively unimportant to the story. What is important is the fact that these reflecting light rays create a series of alternating bright and dark bands . . . and all we are concerned about is that the dark bands represent places along the air-wedge where its thickness is an exact multiple of a half wave length of light.

Since a half wave length of yellow filtered light is known to be eleven millionths of an inch, this means that each dark band



represents an increase of that much in the thickness of the air-wedge or, in other words, the tilt of the optical flat. From here on, it is just simple arithmetic to figure out the difference in height between the gauge being checked and the "Jo" block.

If, for example, three dark bands can be seen in a space of one inch on the "Jo" block (not counting the first or zero thickness band), that means the optical flat slants up thirty-three millionths of an inch at the high end. Therefore, if the gauge being checked is two inches away, it is sixty-six millionths of an inch higher than the "Jo" block.

While we have exaggerated the illustration to show you the principle, you can see how a technician can count some dark bands and measure with an ordinary ruler to determine within a few millionths of an inch how much larger or smaller the gauge is than the "Jo" block. This process, because it is based on interference between light rays, is known as INTERFEROMETRY.

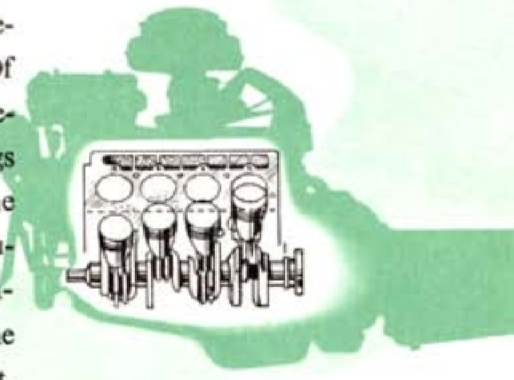
Thus, with such a seemingly indefinite thing as a ray of light, men can measure distances much too small to be seen even with the most powerful microscopes. It is the last word in dependable accuracy because there is nothing more constant and predictable than the characteristics of light. Earthquakes, tides, ice ages, and other upheavals of nature can and do alter the shape and size of our globe. And since the meter is based on the dimensions of the earth, it is based on an inconstant standard . . . although these inconstancies actually are too small and insignificant to have any serious effect on most ordinary everyday measurements. Still they are important in fine scientific work, and, if the Standard Meter Prototype Bar ever happened to be destroyed, it might be extremely difficult to replace it with an exact duplicate based on the measurements of the earth.

Nothing though, can change the wave length of light, so it is the world's most accurate standard of measurement.

Precision on the Production Line

WITH all the dramatic progress we've made in achieving finer and finer degrees of precision, it is so easy to overlook the most important development of all in the science of measuring. After all, it is one thing for a trained scientist to spend days or weeks in a laboratory making a single meticulous measurement. It is quite another for an unskilled factory worker to measure hundreds of pieces per hour with a watchmaker's standard of accuracy.

In many parts of an automobile or a refrigerator, accuracy in the order of thousandths and millionths is essential. It means a lot more than just interchangeability and ease of assembly. Of course, that is important too because the faster and easier things can be made and assembled, the lower they are in price. But accuracy of measurements in manufacturing also means a lot to the customer after he buys a product.



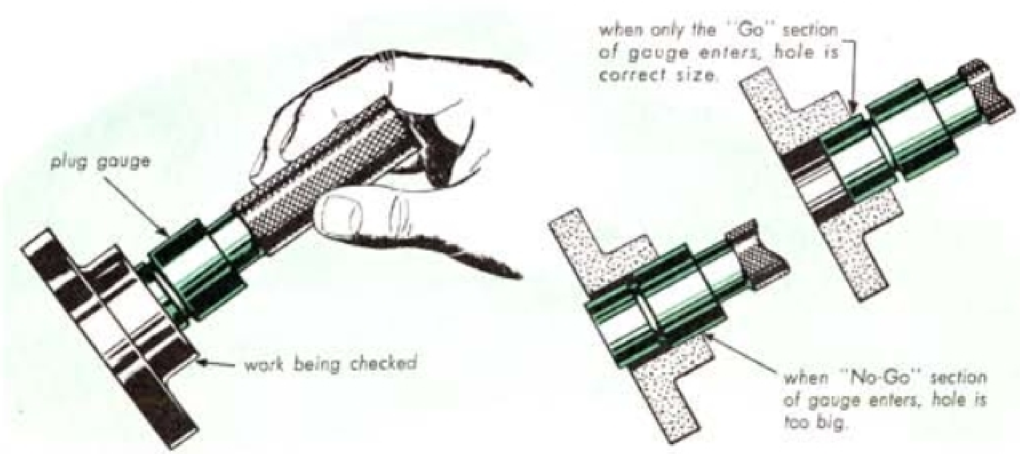
A carburetor jet a thousandth of an inch too big, for example, is just one of the things that could very easily cut down a car-

owner's gasoline mileage by a mile or more to the gallon. Here is a tiny part the average motorist rarely sees, yet the accuracy with which it is made is very important to him every mile he drives his car.

Actually, a carburetor jet . . . and there are several of them, although usually only one controls the flow of fuel for normal driving . . . is just a small piece of brass with a round hole in it. But that hole has to be the right size. If it is too big, gasoline will be wasted. If the hole is too small, the engine may not have enough power or speed . . . or may not even run at all.

Ordinarily, plug gauges are used to measure holes in metal. They are made of steel and are accurately ground with two diameters. The gauge is pushed into the hole to be measured. If the first diameter enters, the hole is big enough. But the second diameter should not enter, otherwise the hole is too big. These are what are called *"go"—"no go"* gauges.

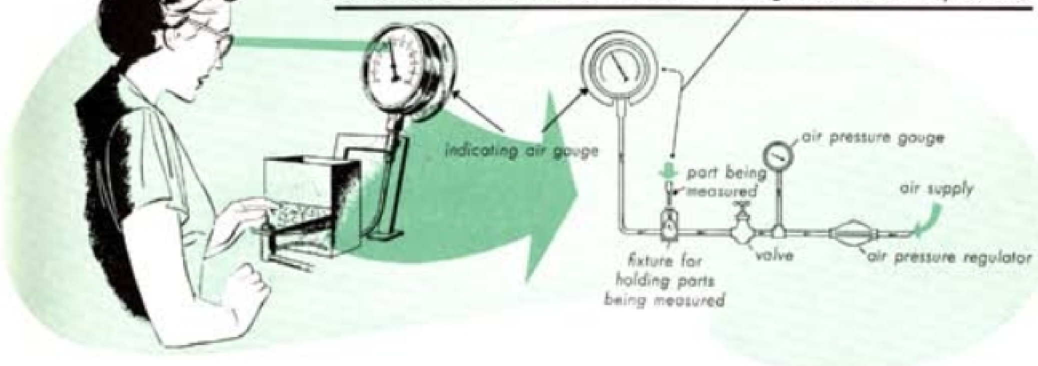
Usually, the difference between the two diameters on a plug gauge is at least 5 to 10 thousandths of an inch. However, this is



too much variation to allow in a carburetor jet . . . remember, every thousandth of an inch variation can mean a mile or more to the gallon. Besides, brass is a comparatively soft metal which can easily be scratched or marred with hard steel. Moreover, there is no way of telling, with a plug gauge, the actual size of a hole that is not perfectly round. Consequently, plug gauges are not practical for measuring the holes in carburetor jets.

However, carburetor jets can be measured much more accurately using fluid as a measuring stick. After all, the carburetor engineer is not as interested in how big the hole is as he is in how much fluid will pass through it in a given length of time. So, a fluid is forced through the hole and the amount of flow is measured.

When part being measured is inserted in the fixture, air flowing through the part gauges its size which is indicated on a large dial that is easy to read.

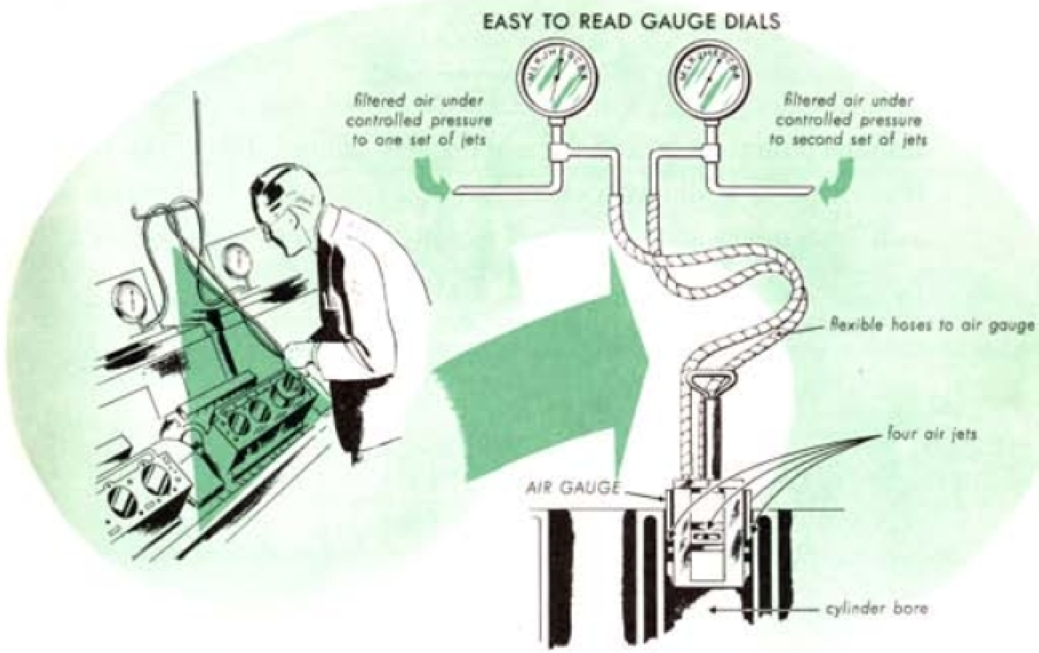


Most of us usually think of fluids as being only liquids. Yet air or any other gas is a fluid as well and they behave much the same as any liquid. At the factory, carburetor jets are measured by forcing air through the hole. Its size can be computed by the amount of air that passes through in a given length of time. Neither gaseous nor liquid fluids can possibly mar or enlarge the carburetor jet, and since this method measures true size whether the hole is perfectly round or not, car owners gain better performance and economy.

Air can be used for measuring holes of almost any size or length. Years ago, a method was developed for measuring rifle barrels with the flow of air. An accurately ground plug gauge was shoved down the barrel. Air was pumped through a series of holes in the periphery of the gauge. The amount of air leaking out between the gauge and the walls of the rifle barrel gave an accurate measure of the diameter of the rifle bore. What's more, this gauge could be moved back and forth throughout the full length of the rifle barrel to make sure it was the same size along its entire length.

This very same method is used today to measure cylinder bores in automobile engines. By using thin air, rather than hard steel, to do the measuring, there is no danger of scratching or marring the finely finished surfaces of the cylinder bores. Also, the workman can be positive of his accuracy because the dimension is read directly on a large dial. It's easy for the workman to read the dimension because the needle may move as much as half an inch. But that half an inch of movement is a terrific exaggeration . . . it represents only 50 millionths of an inch in the cylinder bore!

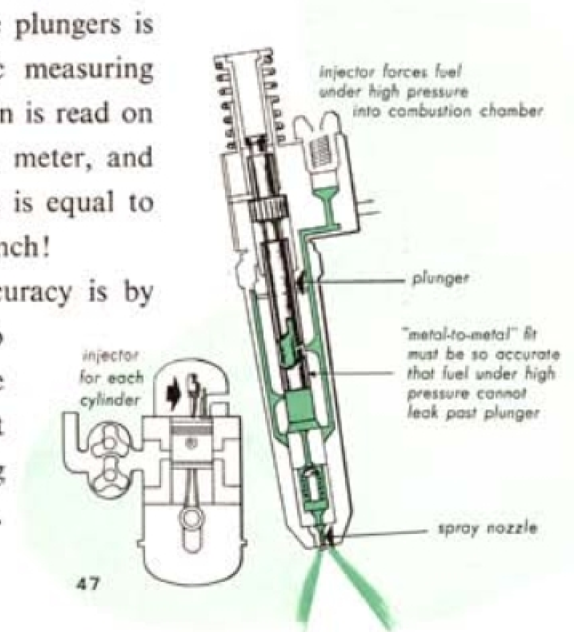
Accuracy also has a lot to do with the fuel economy in a Diesel engine. In these engines, fuel is sprayed directly into the



cylinders. There is a mechanical pump called an injector unit at the top of each cylinder. It has a plunger that forces the fuel out into the cylinder through very tiny holes. The size of these holes, and also the fit of the plunger, must be even more accurate than the parts in most fine watches.

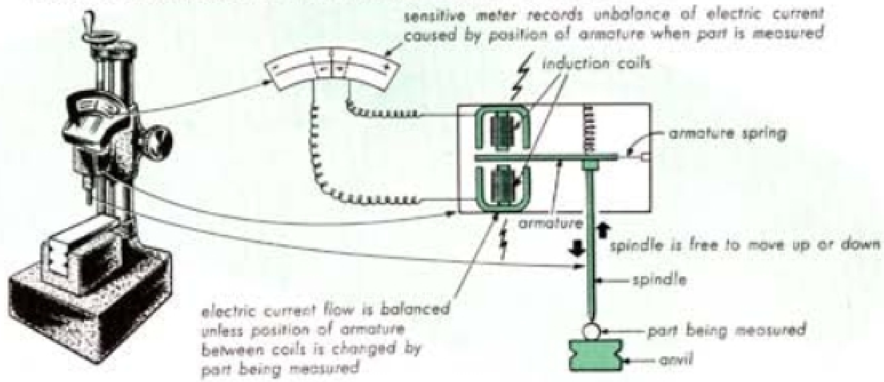
The diameter of these plungers is gauged on an electronic measuring instrument. The dimension is read on the dial of a big electric meter, and each division on the dial is equal to only 10 millionths of an inch!

Such attention to accuracy is by no means the exception to the rule, for gauges of one kind or another are used at nearly every manufacturing step in today's factories.



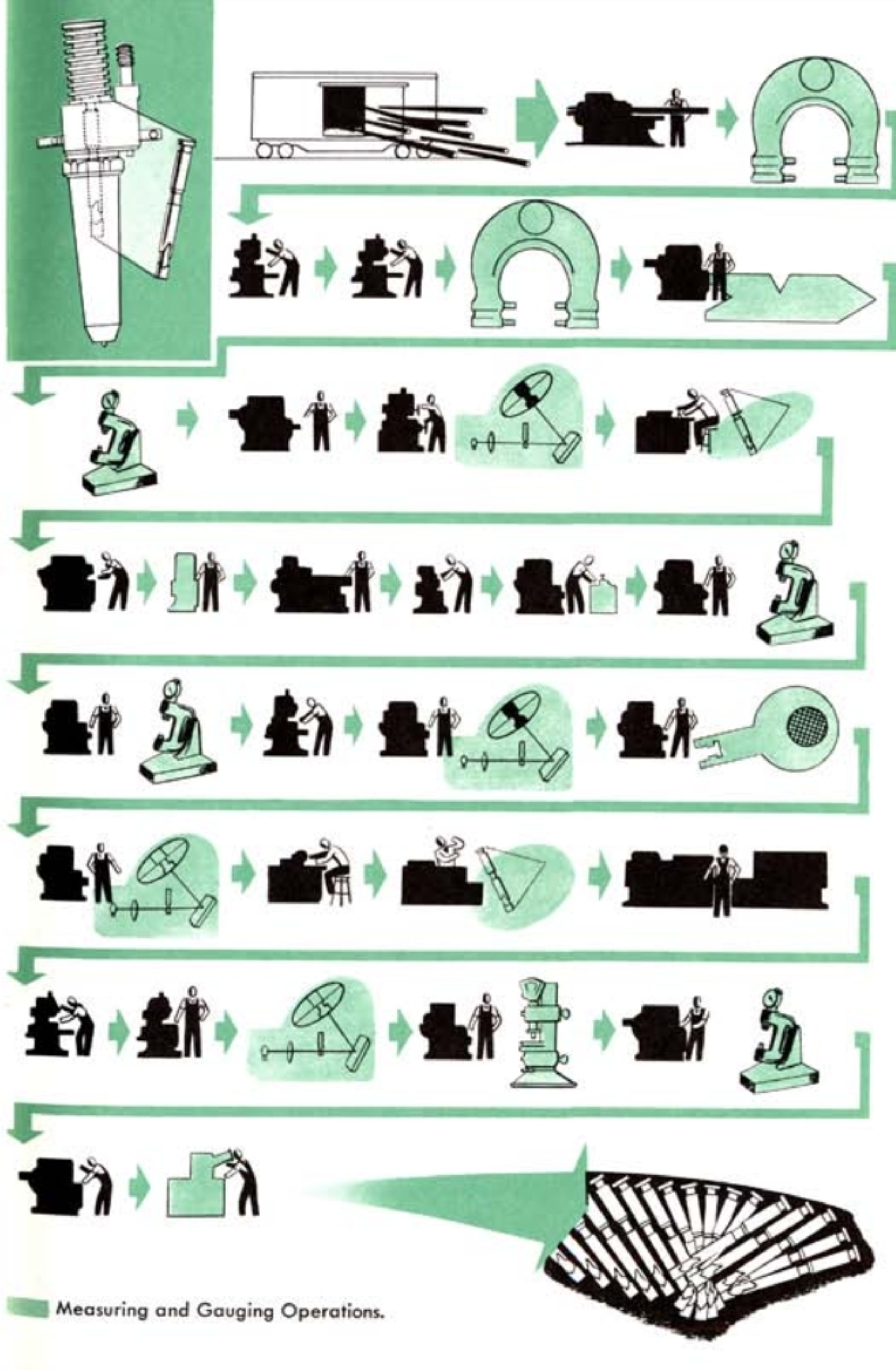
On the opposite page, there is a simplified flow chart of the manufacturing operations in making the plunger for a Diesel injector. It is a simple looking little part about as big around as a lead pencil and about half as long. Yet, this small rod of

ELECTRONIC GAUGE THAT MEASURES WITHIN 10 MILLIONTHS

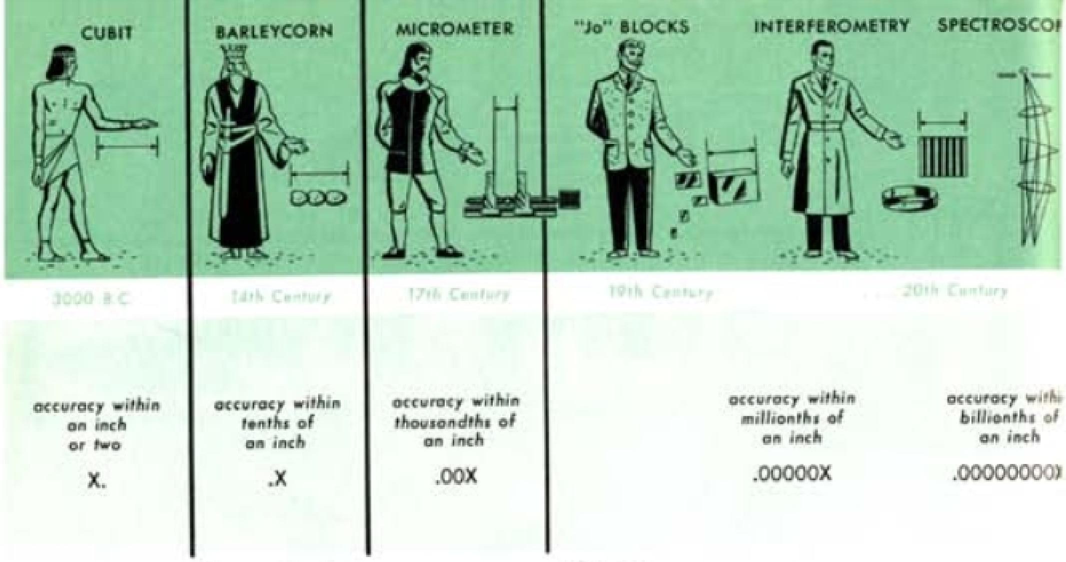


steel is measured and gauged no less than 18 times, with the most important dimension made to an accuracy of 10 millionths of an inch on the electronic gauge.

Many other automotive parts are measured on air and electronic gauges similar to the ones we've just mentioned. It would take a veteran toolmaker a long time to measure that closely with optical flats, but with the ultra-sensitive gauges now used in industry, anyone can achieve that accuracy with ease and as fast as he can push the parts through the measuring machine.



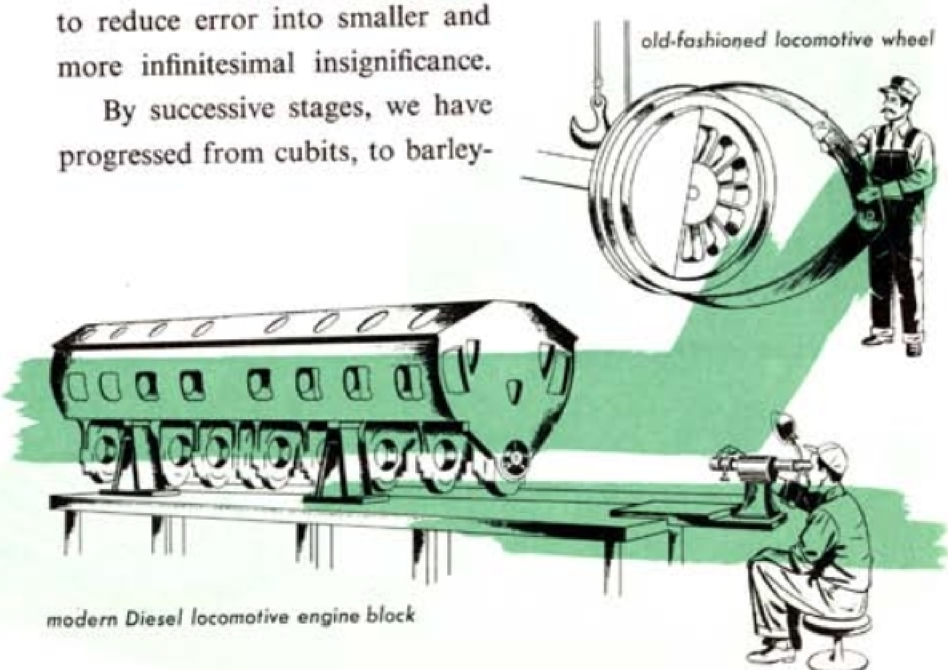
Measuring and Gauging Operations.



The Measure of Tomorrow

No story of progress has ever had any "final" chapter . . . nor will there ever be one for this story on measurements. Since there is no such thing as man-made perfection, there never will be any truly exact measurements. Nevertheless, scientists continue to search for ways and means to measure things ever more accurately . . . always seeking to reduce error into smaller and more infinitesimal insignificance.

By successive stages, we have progressed from cubits, to barley-



old-fashioned locomotive wheel

modern Diesel locomotive engine block

corns, to micrometers, to interferometry. Cubits varied as much as several inches. Barleycorns generally were within 1/10th of an inch of the same size. With micrometers, we can measure within a thousandth of an inch, and interferometry has narrowed the range down to millionths.

But this is still not the end. Even now, measurements are being made in terms of billionths. The scientist working in the field of spectroscopy, instead of speaking in inches of length, uses what are called angstrom units. An angstrom unit is a little less than 4 billionths of an inch!

The spectroscope is an optical instrument used to identify the elements in a substance. There doesn't seem to be much connection between this, another little-known instrument called an interferometer, and a tiny pin-point pool of special mercury that took more than a year to make from a thin sheet of gold in one of the nation's atom piles. Yet these three combine to provide one of the most accurate methods of measurement ever devised by man.

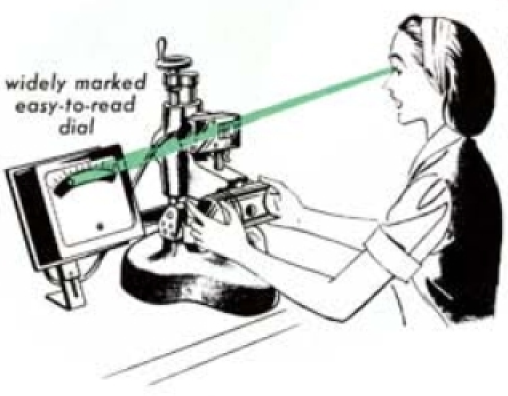
There's nothing secret about this development even though it is connected with our atom bomb program, but it is so highly technical that it is beyond the scope of this booklet. What is really important about it is that, with these instruments, men can now measure with an accuracy of less than a billionth of an inch!

This extreme degree of precision is hundreds of times finer than that which can be obtained with the world's Standard Prototype Measuring Bars. As a matter of fact, they and every other measuring stick in the world could be destroyed . . . yet we could duplicate them all with even greater accuracy than before. A bright green line, originating from this

closely spaced scribe marks.

special form of mercury and measured with the spectroscope and interferometer is the most accurate basis yet discovered for measuring, and very likely will some day be accepted by the whole world as the standard for measuring distances.

While laboratory scientists have thus been blazing the trail towards finer and finer degrees of precision, industrial engineers have been keeping pace with them. They have translated the theory learned in the laboratory and put it to practical use in the shop by devising new methods and techniques that enable workmen to do better, more accurate work.



One of the most important contributions of the industrial engineers is the way they are making gauges more and more foolproof. It used to be that the "feel" of a micrometer or a caliper was very essential in making precision measurements. Usually, only the more experienced machinists and toolmakers had the necessary skill to obtain dependable and consistent readings. And, usually, they were the only ones out in the factory who could read and interpret blueprints.

Today, though, modern gauges are made so that they will give exactly the same reading no matter who is doing the measuring . . . whether it be a nimble-fingered girl or a heavy-handed "wrench-bender" mechanic. Moreover, the person doing the measuring never even has to look at a blueprint . . . in fact, many gauges have no numbers or any other representation of the size of the dimension. All the workman has to do is see that the needle

registers in a broad colored segment on the dial. There is no psychological strain of trying to work within close limits, for, insofar as he is concerned, the allowable sweep of the needle may be as much as half an inch . . . yet he actually may be measuring within 50 millionths or even less.

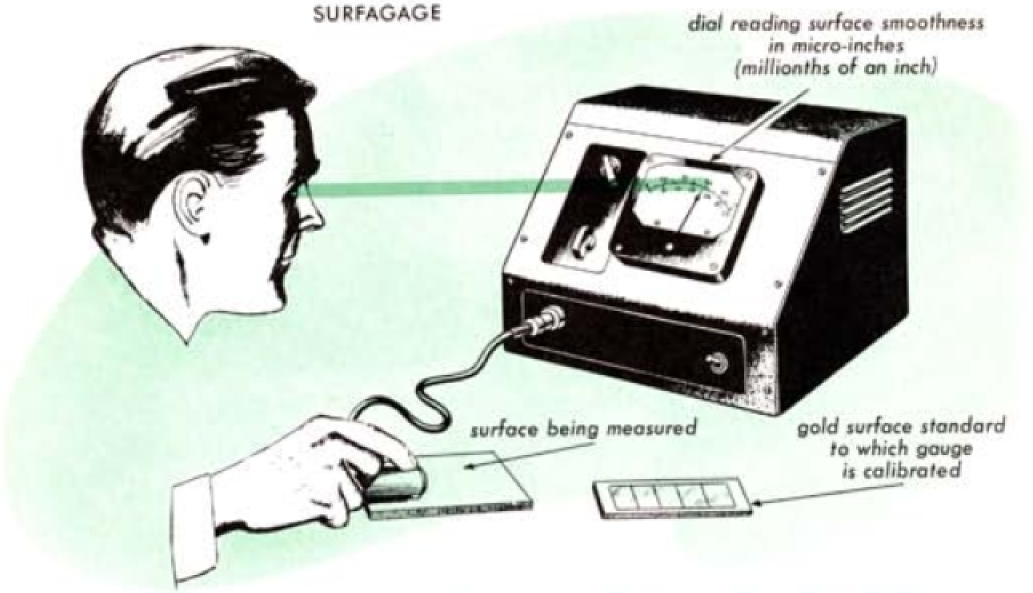
Throughout this booklet, we've concentrated mostly on the measurement of linear dimensions . . . that is, measurements of length. However, the same impressive advances have been made in other fields of measurement . . . weight and time and volume. And, of course, there are many, many other branches of the science. There are measurements of the intensity and pitch of sound . . . the brilliance and hue of color . . . the dampness of air . . . temperature . . . odor . . . smoothness . . .

One of the latest developments in the world of measurements is a method of specifying smoothness. How smooth is smooth?

Anyone can see that smoothness has a lot to do with the way working surfaces wear and how long they last. However, it may come as a surprise to many that the smoothest and shiniest surface is not always the best for wear and durability. Actually a dull surface may be much smoother than one that gleams like a mirror. But even so, a comparatively rough surface may help make a better product. Obviously though, it must be just exactly the right degree of roughness . . . or smoothness . . . and the difficulty always has been to describe it in words alone.

But now the problem has been solved. Research technicians in the laboratories of a leading manufacturer have prepared a brand new set of standards for industry. These standards are

SURFAGAGE



expected to occupy a niche in the world of measurement comparable to that of the government's prototype standards of length. And, from these new standards, will be made very accurate copies . . . copies that will find places in shops and factories throughout the world like the Johansson gauge blocks.

These new standards of surface smoothness have taken form as a series of very finely engraved parallel lines on surfaces of pure gold. The depth of these lines and the distance between them is what creates the standard of surface smoothness.

Industries that have copies of these blocks will use them to calibrate an electronic surface testing machine that works something like a phonograph player. A needle drawn across the surface standard block will generate electrical impulses that will move a sensitive needle across the face of a large dial. The dial will be calibrated in *micro-inches* . . . which are millionths of an inch! The instrument then will be

used to measure the surface of the production part to determine whether or not its smoothness is within the limits of the numbers specified.

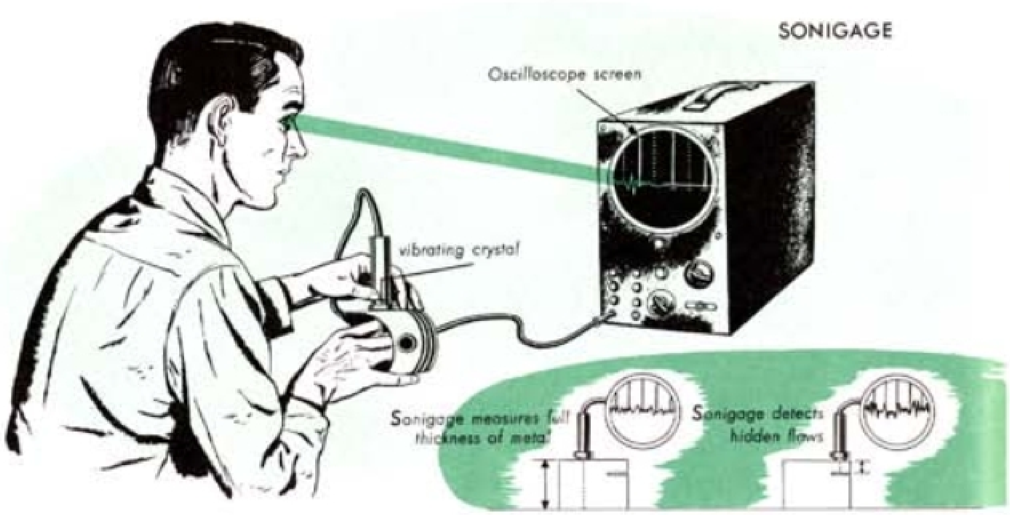
In recent years, industrial engineers have designed another instrument that uses a different one of Nature's yardsticks. It is one that is used in places where none of the others will work. For example, how would you go about measuring the thickness of an eggshell without breaking the egg? This sounds like something only a magician could do . . . yet it is commonplace in modern industry today.

Of course, technicians in factories rarely, if ever, are interested in gauging eggshells. Nevertheless, there are many cases where they have similar problems. Oftentimes, the wall thickness of tanks containing corrosive acids must be checked periodically to make sure they are sound. Measuring the thickness of long, small-diameter tubes also is a difficult task because lengthy calipers are unwieldy and their accuracy is not dependable. And the steel plates in ship hulls have to be gauged occasionally to find those that have to be replaced when they become dangerously weakened by saltwater corrosion.

In these, and many similar cases, a comparatively new instrument called a ***sonigage*** will measure the wall thickness of objects where it is either difficult or impossible to reach more than one of the surfaces.

The sonigage does its job with ultrasonic sound waves. These are the same as regular sound waves except that they are so high in pitch that human ears can't hear them. They are generated by passing a high frequency electric current through a special crystal. This makes the crystal vibrate millions of times a second.

When the crystal is held against the wall to be measured, the



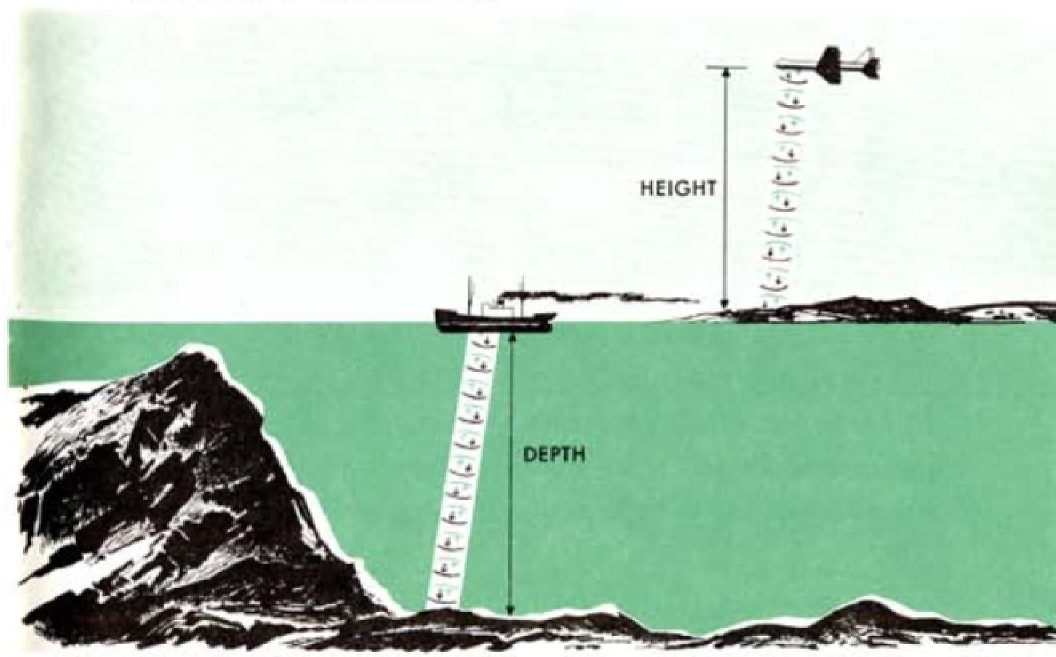
sound waves travel along a tunnel-like path through the metal. When the thickness of the metal and the frequency of the sound wave are in a certain exact relationship with each other, the metal is said to be in resonance with the crystal, which simply means that it is vibrating in harmony with the crystal. By varying the frequency, the operator can tell when the metal walls begin to vibrate because a sharp peak will appear in the wavy line on the oscilloscope screen. An oscilloscope screen is practically the same as a television picture tube. The face of the oscilloscope screen is calibrated in thousandths of an inch.

There are many other interesting variations in this technique of measuring with ultrasonic sound waves and high-frequency radio waves. One of them is the ***fathometer*** used by ships at sea. In this case, a short burst of sound is projected downward through the water from the bottom of the ship. The length of time it takes for the echo to be reflected back from the bottom of the ocean is an accurate measure of the depth of the water.

Very much the same principles are used in the radio altimeters that tell airplane pilots how far they are above the ground. About the only difference between the two is that the radio altimeter uses high-frequency radio waves instead of ultrasonic sound waves.

And radar, one of the most important outposts in our ring of defense against sneak air attacks, is another similar measuring instrument in which extreme precision is vital. It sends out short bursts of ultra-high-frequency radio waves into the sky with the speed of light. When they encounter a solid object like an airplane, the waves are reflected back to be picked up by a radar receiver.

Dancing lines on an oscilloscope screen actually measure in micro-seconds (millionths of a second) how long it took for the radio wave to travel out and back. But to avoid the necessity for converting elapsed time and the speed of light into distance, the meters and dials of a radar unit are calibrated to read directly in yards. Thus, with an extremely accurate time measuring device, it is possible to locate an enemy plane, tell how far away it is, and how rapidly it is approaching.



As dramatic as have been all these advances in the science of measuring, they are no more so than the fundamentals on which they are based. The only reason today's workmen can be more accurate than yesterday's, is that we have learned how to use finer and more dependable "yardsticks." Actually, there have been three distinct revolutions in the choice of standards for measuring dimensions of length.

The first one came when mankind began to realize that measuring short distances with a finger, or a forearm, or a foot, was highly inaccurate because of the differences in men's statures. To avoid these differences, they made measuring rods and sticks that were entirely independent of a man's size.

The second revolution came when Gascoigne showed the world how to measure with screw threads. Whereas always before, men had measured things by direct comparison with a known stand-

ard . . . just as many of us still roughly measure something by laying a ruler alongside it . . . Gascoigne's forerunner of the micrometer made the old direct comparison method out of date for precision measurements.

The third and latest revolution is still underway. For the utmost in accuracy, we no longer use physical yardsticks like the old six-inch ruler or the micrometer. Rather, we use intangible things like electrons, air flow, light waves, supersonic sound waves, and high-frequency radio waves. In these yardsticks, Nature has given us perfect standards for measurement. Neither season nor place has any effect on them. All continue to behave exactly the same as they have ever since the beginning of time, and there is adequate proof that they will continue to do so as long as this world of ours exists.

It seems uncanny the way developments in the science of measuring have coincided with world progress in general. Cubits and Arks were on the same level in the rise of mankind. Micrometers and gauge blocks are intermingled in the same pages of history with the Industrial Age, and mass production, and a high standard of living. And now, at the threshhold of an atomic and jet-propelled era, electrons and waves are the yardsticks. They have brought accuracy of millionths with the possibilities of billionths. Truly, precision is a measure of mankind's progress.

Glossary of Weights and Measures

(All specifications are U.S. standards, and weights are in avoirdupois unless otherwise noted.)

Acre—A square measuring 208.7 feet per side—640 acres per square mile.

Barrel—31.5 gallons—0.11924 cubic meters.

Board Foot—12 x 12 x 1 inches—144 cubic inches—2359.8 cubic centimeters.

Bolt (cloth)—40 yards—120 feet—36.576 meters.

Bucket (British, dry)—4 gallons (British).

Bushel (dry)—4 pecks—0.035239 cubic meters.

Cable Length—240 yards—720 feet—219.46 meters.

Carat (International Metric)—3.086 grains (troy).

Carat (for measuring fineness of gold)—1/24th part.

Centigram—0.1543236 grains—0.01 grams.

Centiliter—0.33815 fluid ounce—0.61025 cubic inches—0.01 liters.

Centimeter—0.032808 feet—0.3937 inches—0.01 meters.

Cord of wood—4 x 4 x 8 feet—128 cubic feet—3.625 cubic meters.

Cubit—18 inches—45.72 centimeters.

Decigram—1.543236 grains—0.1 grams.

Deciliter—3.38147 fluid ounces—0.1 liters.

Decimeter—3.93700 inches—0.3280833 feet—0.1 meters.

Dekagram—0.35273957 ounces—10 grams.

Dekaliter—1.13513 pecks—9.08102 quarts (dry)—10 liters.

Dekameter—32.8083 feet—393.70 inches—10 meters.

Drachm (British, fluid)—1/8th ounce (British, fluid).

Dram—1/16th ounce.

Dram (fluid)—1/8th ounce (fluid).

Ell—45 inches—114.30 centimeters.

Em (Pica)—1/6th inch—0.42333 centimeters.

Fathom—2 yards—6 feet—1.828804 meters.

Firkin—9 gallons—34.068 liters.

Foot—12 inches—0.3048 meters.

Furlong—1/8th mile—660 feet—201.168 meters.

Gallon—4 quarts—8 pints—3.7853 liters.

Gallon (British Imperial)—1.20094 gallons (U.S.)—4.54596 liters.

Gill—1/4 pint—4 ounces (fluid)—0.118292 liters.

Grain—0.0022857 ounces—0.064798918 grams.

Gram—0.0352739 ounces—15.4324 grains.

Great Gross—144 dozen.

Gross—12 dozen.

Hand—4 inches—10.160 centimeters.

Hectare—2.471044 acres—11959.85 square yards—10,000 square meters.

Hectogram—3.52739 ounces—100 grams.

Hectoliter—2.8378 bushels—100 liters.

Hectometer—109.3611 yards—328.08 feet—100 meters.

Hogshead—63 gallons—2 barrels—0.23848 cubic meters.

Hundredweight—100 pounds (short)—112 pounds (long).

Inch—1/12th foot—1/36th yard—25.40005 millimeters—2.54 centimeters.

Kilderkin (British)—18 gallons (British)—0.081830 cubic meters.

Kilogram—2.2046223 pounds—1000 grams.

Kiloliter—264.18 gallons—35.316 cubic feet—1000 liters.

Kilometer—0.62137 miles—3280.8 feet—1000 meters.

League—3 miles—4.8280 kilometers.

Litèr—1.056710 quarts—0.035316 cubic feet.

Meter—39.37 inches—1.093611 yards—3.280833 feet.

Micron—39.37 millionths of an inch.

Mile (nautical)—6080.2 feet—1.85325 kilometers.

Mile (statute)—5280 feet—1.60935 kilometers.

Milligram—0.0000352739 ounces—.001 grams.

Milliliter—0.0338147 ounces (fluid)—0.2705179 drams (fluid)—.001 liters.

Millimeter—0.03937 inches—.001 meters.

Nail (British)—2.25 inches—5.715 centimeters.

Noggin (British)—5 ounces (British, fluid)—142.06 cubic centimeters.

Ounce (British, fluid)—0.00625 gallons (British)—28.4130 cubic centimeters.

Ounce (U.S., fluid)—1/16th pint—0.0295729 liters—29.5737 cubic centimeters.

Ounce—1/16th pound—28.349527 grams.

Pace (British)—30 inches—76.2 centimeters.

Palm (British)—3 inches—7.62 centimeters.

Peck—1/4 bushel—8 quarts—8.80958 liters.

Peck (British)—2 gallons (British)—9.0919 liters.

Pennyweight (troy)—0.054857 ounces—1.55517 grams.

Perch—1 rod—16.5 feet—5.0292 meters.

Perch of masonry—16½ x 1½ x 1 feet—24.75 cubic feet—.70085 cubic meters.

Pint (dry)—1/2 quart—0.550599 liters.

Pint (liquid)—1/2 quart—16 fluid ounces—0.473167 liters.

Pint (British, liquid)—1.20094 pints (U.S.)—0.56825 liters.

Point (printer's type)—1/72 inch—0.035278 centimeters.

Pole (British)—1 rod—5.5 yards—16.5 feet—5.0292 meters.

Pottle (British)—2 quarts (British, liquid)—2.273 cubic decimeters.

Pound—16 ounces—0.4535924 kilograms.

Puncheon (British)—70 gallons (British)—84 wine gallons.

Quart (British, liquid)—1/4 gallon (British)—1.13650 liters.

Quart (U.S., liquid)—2 pints—32 ounces (fluid)—0.946333 liters.

Quart (dry)—1/32 bushel—0.038889 cubic feet—1.10120 liters.

Quire—25 sheets.

Ream—500 sheets.

Rod—5.5 yards—16.5 feet—5.029210 meters.

Rood (British)—1/4 acre—1210 square yards—10.117 square dekameters.

Rope (British)—20 feet—6.0960 meters.

Sack (British)—3 bushels—0.10911 cubic meters.

Skein—120 yards—360 feet—109.73 meters.

Span—9 inches—22.86005 centimeters.

Stere—1 cubic meter.

Stone (British)—14 pounds—6.350 kilograms.

Ton (short)—2000 pounds—907.185 kilograms.

Ton (long)—2240 pounds—1016.047 kilograms.

Township—36 square miles—93.240 square kilometers.

Tun—252 gallons—953.8956 liters.

Yard—3 feet—36 inches—0.91440183 meters.

COMMON U.S. WEIGHTS AND MEASURES

Measures of Length:

1 mile—1760 yards—5280 feet.

1 rod—5.5 yards—16.5 feet.

1 yard—3 feet—36 inches.

1 foot—12 inches.

Dry Measure:

1 bushel—1.2444 cubic feet—2150.42 cubic inches.

1 bushel—4 pecks—32 quarts—64 pints.

1 peck—8 quarts—16 pints.

1 quart—2 pints.

Liquid Measure:

1 gallon—0.1337 cubic feet—231 cubic inches.

1 gallon—4 quarts—8 pints—32 gills.

1 quart—2 pints—8 gills—32 ounces (fluid).

1 pint—4 gills—16 ounces (fluid).

Commercial Weight:

1 gross or long ton—2240 pounds.

1 net or short ton—2000 pounds.

1 pound—16 ounces—7000 grains.

1 ounce—16 drams—437.5 grains.

METRIC CONVERSION TABLES

Measures of Length:

1 mile—1609.35 meters—1.60935 kilometers.

1 yard—0.91440 meters—91.440 centimeters.

1 foot—0.304800 meters—30.4800 centimeters—304.800 millimeters.

1 inch—0.0254 meters—2.54000 centimeters—25.4000 millimeters.

1 kilometer—0.62137 miles—1093.6 yards—3280.8 feet.

1 hectometer—109.3611 yards—328.08 feet.

1 dekameter—10.93611 yards—32.808 feet—393.70 inches.

1 meter—1.093611 yards—3.2808 feet—39.37 inches.

1 decimeter—0.32808 feet—3.937 inches.

1 centimeter—0.032808 feet—.3937 inches.

1 millimeter—0.0032808 feet—0.03937 inches.

Measures of Weight:

1 gross or long ton—1.0160470 metric tons—1016.0470 kilograms.

1 net or short ton—0.907185 metric tons—907.185 kilograms.

1 pound—0.4535924 kilograms—453.5924 grams.

1 ounce—28.349527 grams.

1 grain—0.064798918 grams—64.798918 milligrams.

1 kilogram—2.2046223 pounds—35.273957 ounces.

1 hectogram—3.52739 ounces.

1 dekagram—0.35273957 ounces—5.64383 drams.

1 gram—0.00220462 pounds—0.0352739 ounces—0.564383 drams.

1 decigram—1.543236 grains.

1 centigram—0.1543236 grains.

1 milligram—0.01543236 grains.

Measures of Liquids:

1 gallon—3.7853 liters.

1 quart—0.946333 liters.

1 pint—0.473167 liters.

1 gill—0.118292 liters.

1 fluid ounce—0.0295729 liters—0.295729 deciliters—29.5729 milliliters.

1 kiloliter—264.18 gallons.

1 hectoliter—26.418 gallons.

1 dekaliter—2.6418 gallons—10.5671 quarts.

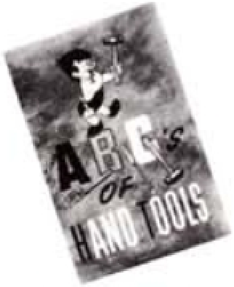
1 liter—1.056710 quarts—2.1134 pints—8.4538 gills—33.8147 fluid ounces.

1 deciliter—3.38147 fluid ounces.

1 centiliter—0.33815 fluid ounces—2.705179 fluid drams.

1 milliliter—0.033815 fluid ounces—0.2705179 fluid drams.

OTHER BOOKLETS OF A SIMILAR NATURE



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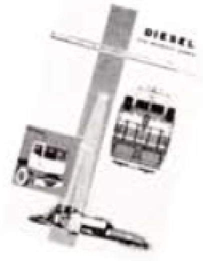

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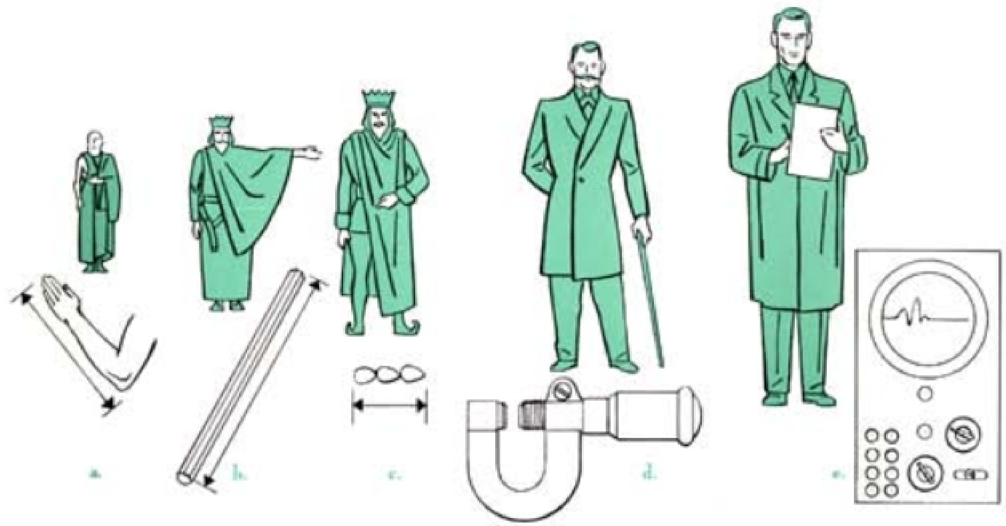

a. *Cubit,* one of the earliest forms of measurement.

b. *The Iron Ulna,* one of the first standards.

c. *Barleycorns,* an early standard that was universally available.

d. *Micrometer,* the first precision measuring instrument.

e. *Oscilloscope,* one of the many modern high-precision measuring instruments.

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