



Sceptre Application Notes: Gears and Gearing Industry

Gears have been manufactured for hundreds of years since humans have had the need to transfer one form of mechanical energy to another. Gear making is a science that evolved over those years. Much of gearing historic development and nomenclature is rooted in the technology of the time. Computer technology is a new comer that has greatly impacted industry in only the last 30 years.

The classic gearing gage lab consisted of several machines/instruments that could test gears in both functional and dimensional analytical terms. The modern CMM (Coordinate Measuring Machine) by contrast is a highly discrete and accurate digitizer that can only feed raw coordinates to a computer. The computer intern must convert that data so it relates to the function and manufacturing techniques used in making the component.

It should be no surprise that the classic gear lab addressed those needs. The instruments found there were the best that the technology of the time could deliver so that gears of high quality (for the time period in question) could be manufactured. Classic gear inspection consisted of several sophisticated machine/instruments that involved some complex mechanical mechanisms that simulated the manufacturing process and functional needs of the end result gear.

INVOLUTE PROFILE

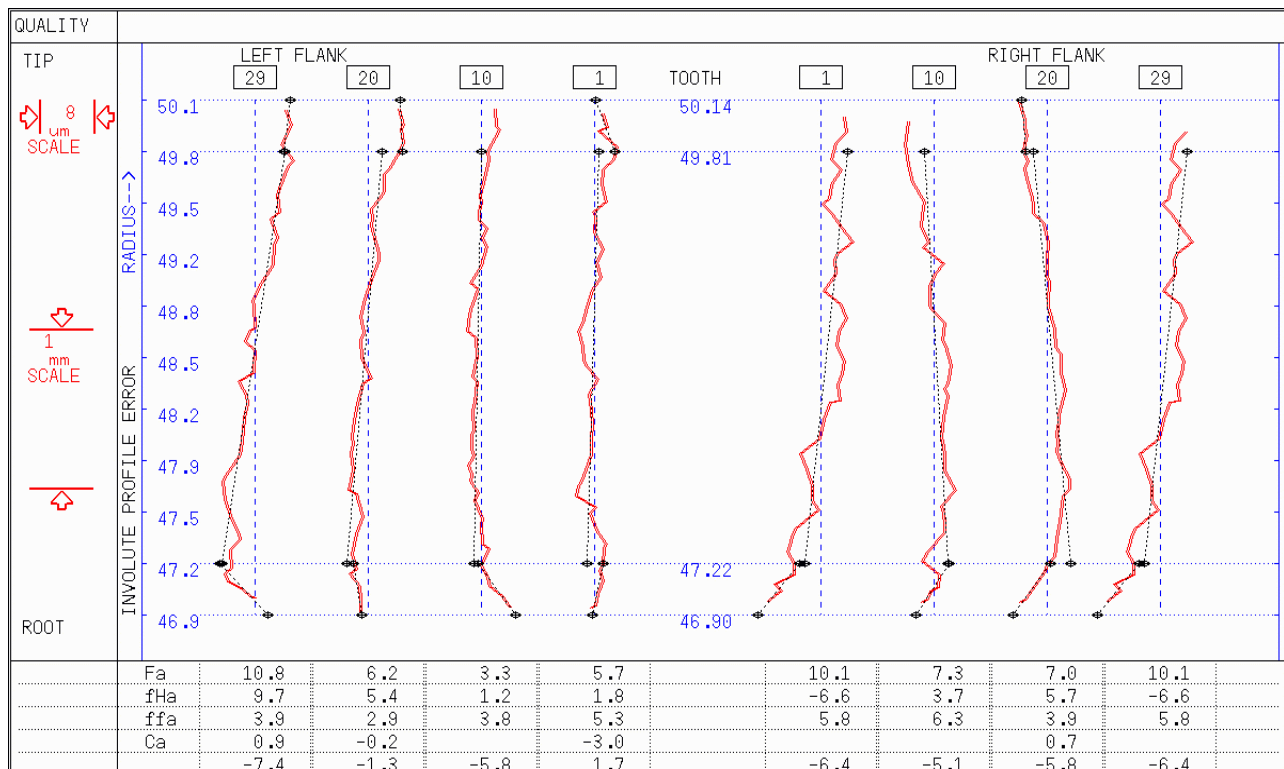
In almost all medieval castle movies we see huge gears made with round wooden pegs that draw up the bridge over the moat. In reality almost all of today's gearing is based on involute tooth profile as opposed to round or circular profiles. An involute profile sort of looks like an arc at first glance but it is a shape defined by mathematics. It is a shape that would be defined by the end of a string that is held taught while it is unwrapped around a cylinder. The cylinder is called the base diameter and it defines a unique path for the end of the string. The string forms a tangent to the cylinder. The angle of that tangent line is called the roll angle. The roll angle is zero where the end of the string crashes into the cylinder.

Involute profile gears have the major advantage that two perfect gears meshing together would have continuous points of contact on opposing teeth. So no change of speed and an even load of energy transfer between the two rotational axes occur. In theory this is true but the shape is generally crowned or modified because the gears will deflect under load or has been modified to reduce noise and increase efficiency.

The pitch diameter is the place where the work is being done. Usually it is right smack in the center of the gear and is the effective diameter of a gear in a set when computing the gear ratio or reduction.

An involute checker was a device that turned the gear as a function of the roll angle while through a complex set of cams and mechanical settings, which moved an indicator along the nominal, involute profile. A chart recorder then recorded the output of the indicator as a function of the roll angle. This chart was then the basis and reference for modifications. Terms such as K-chart and X-chart were tolerance zones and nominal shapes that overlaid the chart recording.

This was obviously a time consuming tedious testing process since the roll angle and involute cams and levers needed to be synchronized together along with a null point of the indicator. Rarely would an entire gear (every tooth) be tested for profile. Since teeth are generally generated in a repetitive cutting process a small



sample of teeth was considered adequate. In most standardized reporting formats today 4 teeth evenly spaced is considered adequate profile testing.

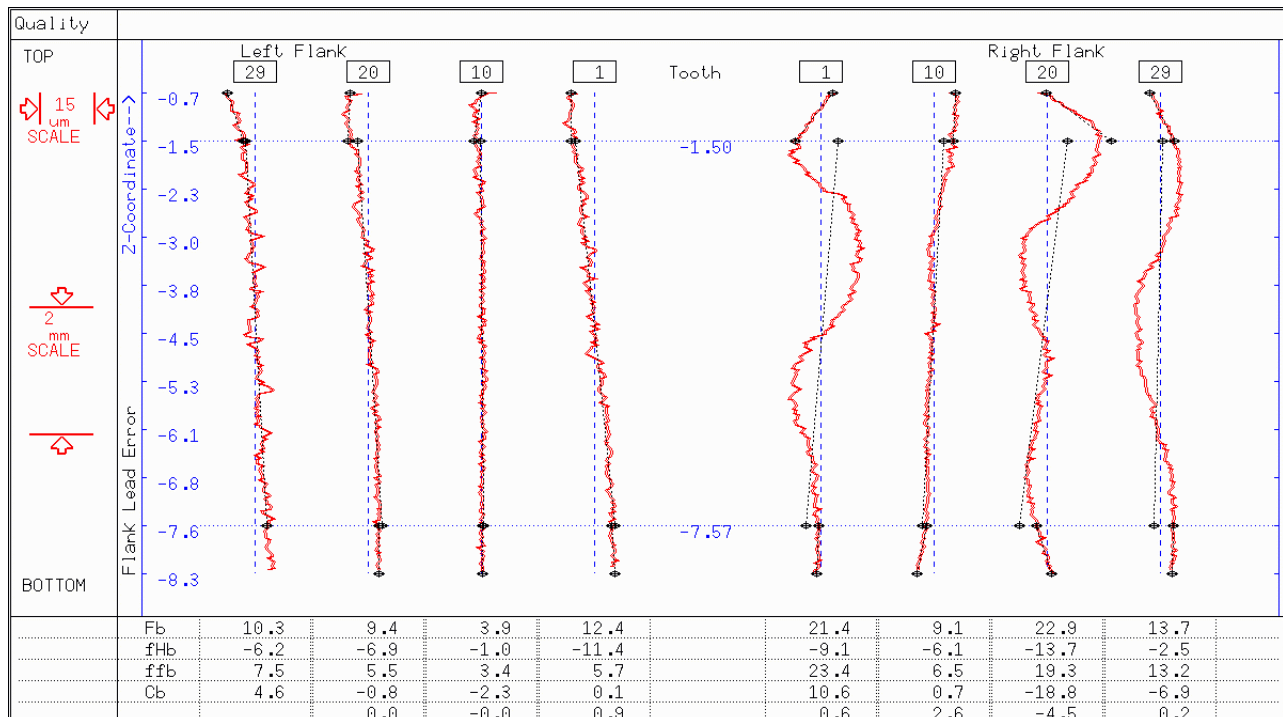
With current Scanning CMM technology involute testing is a simple cross sectional scan across the face of the tooth in a plane perpendicular to the gear rotational axis. A simple spur gear can be adequately accessed by a standard 3 linear axis CMM. Helical gears on the other hand present an access problem that requires either a complex stylus cluster or a rotary table.

The CMM was developed as a substitute to the dedicated machines. The evaluation and reporting was modeled around those instruments. Instead of classical coordinate curve representations the output was bent to simulate the strip chart recording of the original involute profile tester.

Simulated CMM output of an involute profile tester, displays four teeth equally spaced about the gear. The vertical axis is the radial distance to the center axis and the horizontal axis is the deviation from the nominal involute.

Gear Lead Tester

A lead tester was an instrument that added a significant 3rd dimension to the testing. The Z-axis along the axis of rotation was, through belts and gears, actuated in a manner that related Z position to roll angle. Like the involute tester the



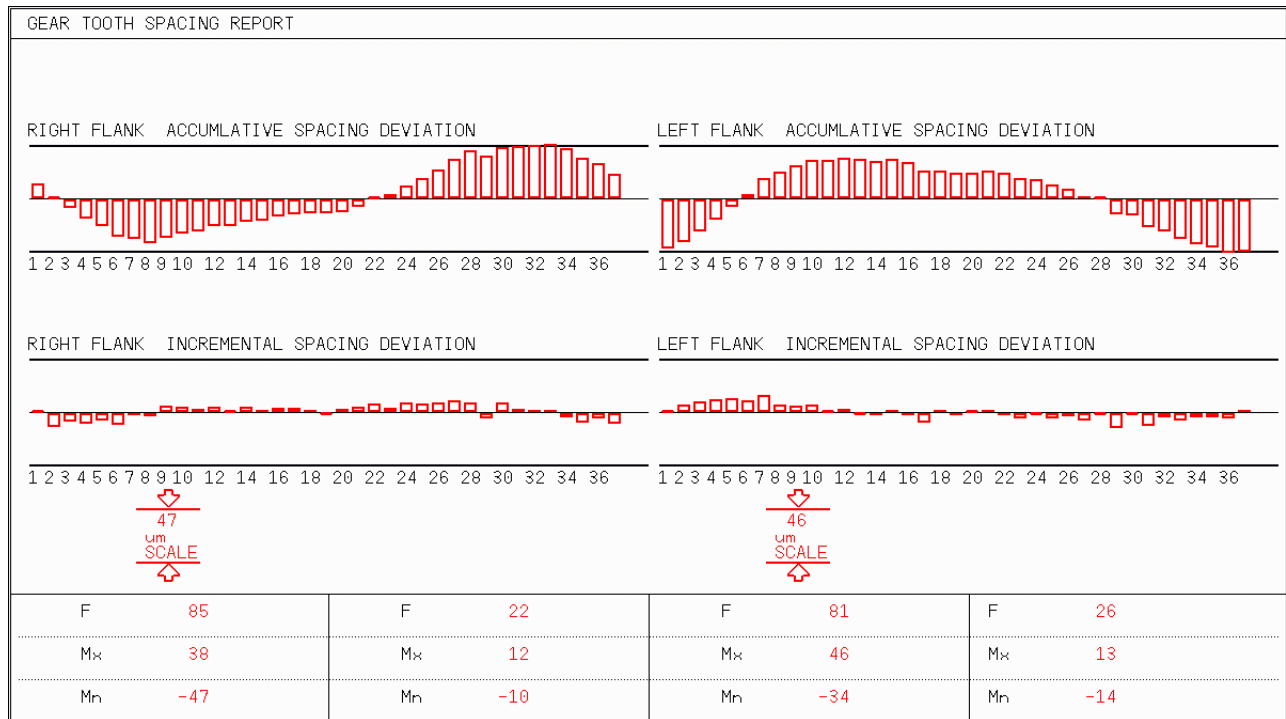
indicator now moved in a nominal helix and the strip chart output was deviation from that helix.

Just like the involute profiles, the lead strip chart was just the starting point of the evaluation and modification of those shapes, usually crowns, were superimposed on that chart. The vertical axis is the Z axis position and the horizontal axis is the indicator movement or deviation from a nominal helix.

Tooth Spacing Testing

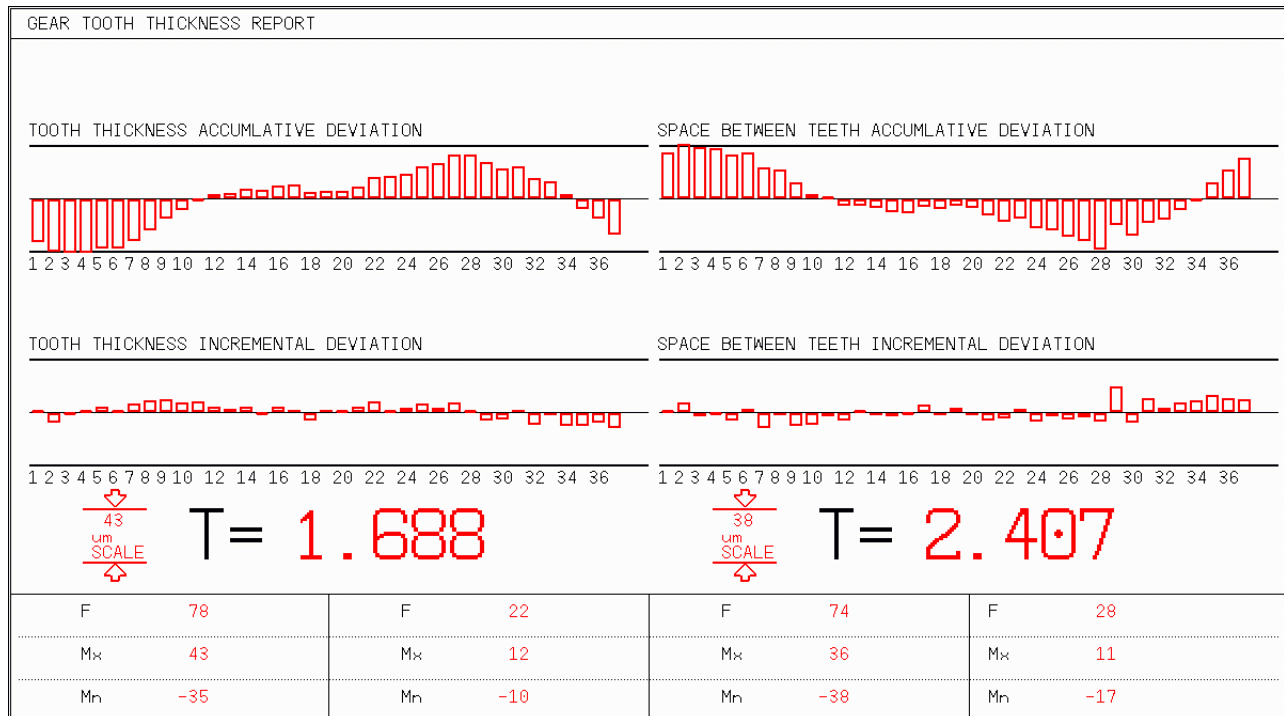
The involute and lead testers were instruments that were developed to just check the shape of tooth form. No information is obtained from them as to the position or location of the tooth. A variety of different types of instruments and methods were employed to determine the tooth location.

Today the CMM can be programmed to probe each tooth face on the pitch diameter.



Tooth Thickness Testing

Tooth thickness is critical feature of the manufacturing process and performance of the gear. Likewise it required special techniques, fixtures and equipment to measure the tooth thickness in the classic gear lab. For CMM methodology the spacing data obtained above was derived from the coordinate location of the teeth at the pitch diameter. That data, when analyzed differently, contains the thickness information.



In effect the CMM has that data for free and requires just the evaluation and reporting.

Roll Tester (Run-out testing)

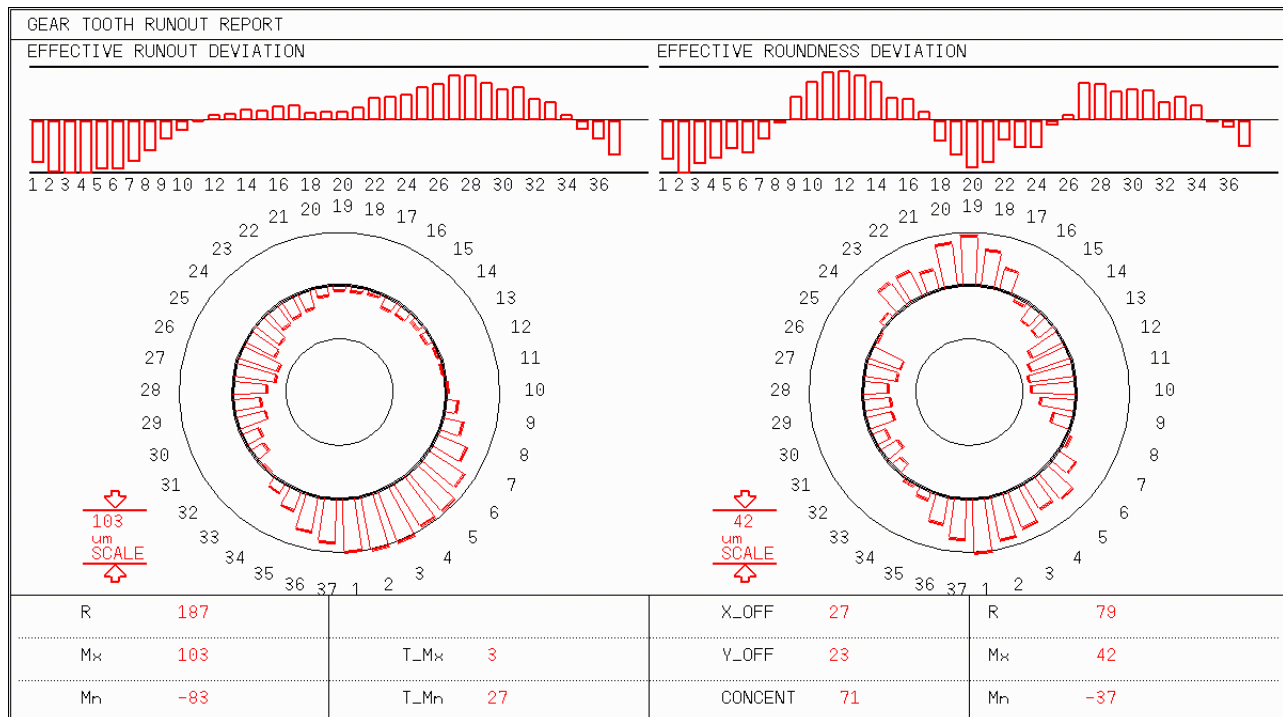
One of the most critical and necessary tools in the classic gear lab was a roll tester. Unlike the other instruments that attempted to measure dimensions or specific material conditions on a gear, the roll tester combined this metrology with functional testing.

A dual spindle device where the test gear was meshed or run against a master gear. One spindle was on a movable axis and a pre-load was applied between the gear sets. If the test gear had poor dimensional quality, then the net effect would be

some relative motion between the two spindles which was monitored again with a strip chart recorder.

Obviously this was not as discrete and analytic in terms of determining where the problem lies but it was a relatively fast overall check of the quality of the gear. The frequency and magnitude of that motion would give an expert a hint as to where the dimensional problem might lie. And that would begin the search using the other more dimensionally specific testing methods.

There are, however, hidden costs and problems with roll testers. The largest problem is with the master gears, which have to be precisely manufactured, and its uncertainties recorded. Any errors are directly superimposed on the roll test data. The CMM, in contrast, has the raw data stored already and requires the actual data for analysis and reporting tools to isolate this functional characteristic of the gear.



What If?

Gears are work pieces where the metrology and error sources have complex interactions with net performance. The classic gear lab attempted to make a variety of tests that were feasible to that time period to qualify gears.

Computers now allow a much more raw unfiltered basic set of coordinates to be massaged and processed with the same results.

What if we removed the run-out of a gear? How would the tooth spacing look? On a previous Gear Tooth Spacing Report we have a spacing chart with 85um variation. If we remove the run-out component, then the spacing is only 29um shown below. One metrological variable can make another appear far different than it really is.

