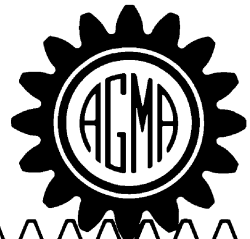


How to Inspect Large Cylindrical Gears With an Outside Diameter of More Than 40 Inches

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American Gear Manufacturers Association



TECHNICAL PAPER

How to Inspect Large Cylindrical Gears With an Outside Diameter of More Than 40 Inches

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Following the general trend, increasingly high quality requirements are also being made on large gears.

Examples include gears for large earth movers, ship's gears, cement mills, rolling mill drives and the latest wind power gears. The demands for a smaller structural volume with simultaneously higher power and lower noise emission are particularly clear here.

Approaching these limits, combined with the refined calculation methods for designing a gear, demands precise inspection of the required flank geometry on the gears used, in order to ensure the necessary functional safety under load. This means that clearly defined corrections to the gear flanks such as depth crowning and crowning, root and tip relief, as well as lead corrections, must be specifically producible and verifiable.

The article shows the design and function of the relevant machines used for individual error measurement, i.e. lead and profile form, as well as gear pitch and runout.

A distinction is made here between different types of inspection machines – between stationary, CNC-controlled gear measuring centers for checking all relevant parameters on gears, and transportable equipment for checking individual parameters directly on the gear cutting or gear grinding machine. Important points such as preparatory measures before a measurement, including workpiece – axial position definition, pre-alignment of the system etc. are also taken into account here.

Following on from this, practical measurement examples with evaluation examples, measurement times etc. are also described, including the conditions when inspecting large internal gears.

The article is rounded off by a description of integrated measuring devices on gear processing machines, as well as their advantages and disadvantages.

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HOW TO INSPECT LARGE CYLINDRICAL GEARS WITH AN OUTSIDE DIAMETER OF MORE THAN 40 INCHES

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1.0 Introduction

Large cylindrical gears have been used for a very wide range of drives since the beginning of industrialization. Due to the size of these workpieces, however, it was only possible to check quality-relevant features on these gears to a very limited extent.

In addition to simple manual inspection devices, e.g. for the determination of the individual component error, or mechanically controlled inspection machines for the definition of profile and lead deviations, large gears were almost exclusively evaluated by means of a test run with definition of the contact pattern. Official acceptance of large gears after a test run also remains obligatory today in many large companies.

However, modern CNC-controlled systems are available today, which allow individual parameters to be checked on large gears, thus enabling control of the manufacturing process and subsequent production of a quality record.

The design and functioning of such systems are described in the following contribution and supplemented with practical application examples.

2.0 Basic design and function of stationary gear measuring machines

CNC-controlled gear inspection machines for smaller gears have already been successfully used in the industry for many years. Starting from the known measuring tasks of profile, lead, pitch and runout on cylindrical gears, these machines offer a much greater diversity of application on the basis of their technology. Ultimately, an extended software package is all that is required to inspect worms and wormgears, bevel gears or even gear cutting tools such as hobs, shaving and shaper cutters.

Appropriate individual error inspection machines are also available for workpieces up to 2600 mm (102") outer diameter.

Basically, CNC-inspection machines consist of the following components:

- Basic machine bed with rotational axis and linear measuring axes
- CNC-control for executing measuring movements and forming measured value

- Evaluation computer system for programming measuring runs and evaluating measurement results, including documentation via printer
- Evaluation software for inspecting a diverse range of gear-related workpieces.

Figure 1 shows an overall view of a CNC-controlled inspection machine for workpieces up to 2000 mm diameter.

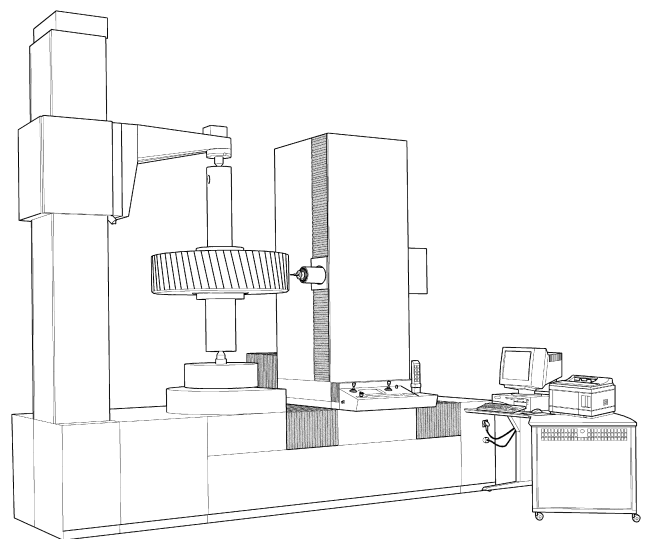


Figure 01: CNC-controlled gear inspection machine

The components mentioned above can be easily identified. The functioning of a CNC machine is comparable to the functioning of a mechanically controlled inspection machine for cylindrical gear measurement. The generating principle of an involute is used during profile measurement. Further parameters can also be checked on cylindrical gears by the use of coordinate movements in one or more axis.

In the case of a CNC-controlled inspection machine, instead of mechanical drive elements such as rolling disks and friction bars electronically controlled individual drives are used on the axes. The functional interrelationship is shown in Figure 2. The measuring movement for generating the involute form occurs through a coupled movement of rotational axis C, including workpiece with the linear axis X, and the mounted probe system. The coupling ratio (transmission ratio) depends on the technical data of the cylindrical gear to be inspected. In addition, each axis is equipped with an M1/M2 drive motor as well as the relevant angle/length measuring system.

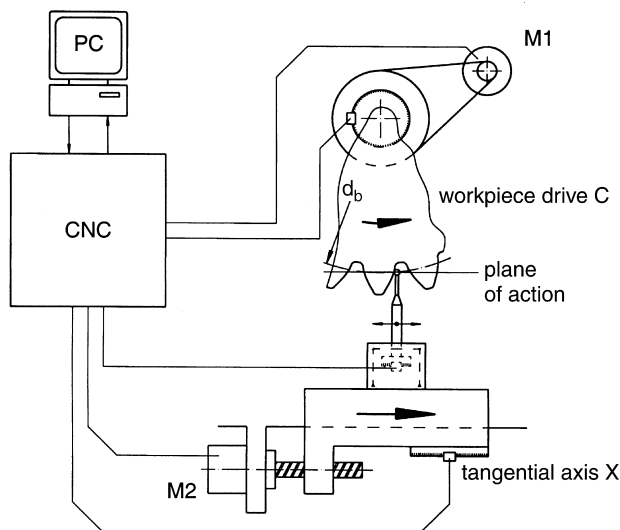


Figure 02: CNC-controlled profile measuring (principle)

The synchronization of the movement cycle is ensured by the CNC control. The probe system thus directly records the profile deviations of the test piece. Further representation and evaluation of the measuring curves subsequently occurs via a PC computer. The inspection cycle for lead measurement on cylindrical gears is generally the same, except that in this case a coupled measuring movement of axes C and Z (Figure 3) is executed in relation to the nominal lead (base helix angle β_b). Depending on the measuring task, diverse axial combinations can be implemented, both for continuous and for individual point probing.

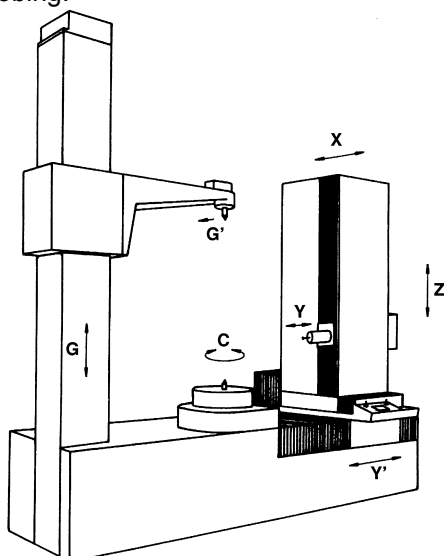


Figure 03: Axes of a CNC-controlled gear inspection machine (example)

2.1 Mechanical construction and probe system

The basic component of an inspection machine is the machine bed, which should be designed as compactly and rigidly as possible, so that it can also accept high workpiece weights without the overall geometry being affected. Gray cast iron has proven itself as the construction material of choice, with reli-

able achievement of these properties. Other materials are also well proven.

In the case of a workpiece loading above 10,000 kg in weight, as may occur with appropriate inspection machines, a stable bed structure alone is not sufficient, but a bond with a stable foundation must be produced. A specially designed foundation is also important, in order to protect the inspection machine from the effects of external vibrations.

The superstructures of the X, Y, Z-linear axes and the C-rotational axis are also made of cast iron, with fitted prestressed, backlash-free and highly accurate anti-friction guideways. In addition, the selected material combination guarantees a high geometrical resistance to the effects of temperature. In order to be able to avoid influences, fluctuations or noise when recording measured values, direct drives without mechanical drive elements have successfully become established, both for the rotary table (high-pole servomotor) and for the linear axes (linear motor), in addition to conventional drives, e.g. via friction gears or ball screws.

In order to be able to deal with large differences in diameter in the case of large cylindrical gears or gear shafts, a machine design like the one shown in Figure 3 and 4 is advantageous. The basic unit with X- / Y- / Z-measuring axis can be moved via an adjusting axis Y' as close as possible to the outer diameter of the gear to be inspected. The actual probing of the gear or defined reference surfaces can then occur via the actual Y-axis. This machine design also enables gear shafts with several gears to be inspected in a mounted status at one clamping (Figure 5).

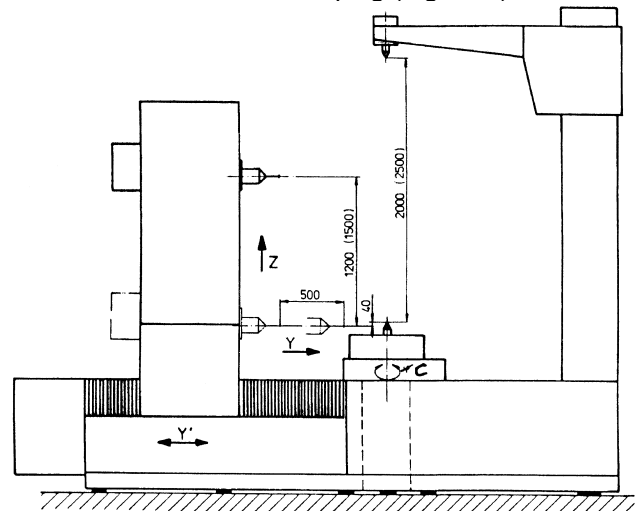


Figure 04: Example of traversing paths – Gear inspection machine for large workpieces

In addition to the practice of mounting large workpieces exclusively "unsupported" on the rotary table of the C-axis or in conjunction with face plates (Figure 5), there is often also the requirement to mount smaller workpieces or gear shafts between centers. In this case, an additional column with tailstock is required. The column is adjusted mechanically and the

upper center can be swung to the side to facilitate workpiece loading. As the operator must coordinate several activities during workpiece loading, a cable-free remote control is particularly helpful (Figure 6).

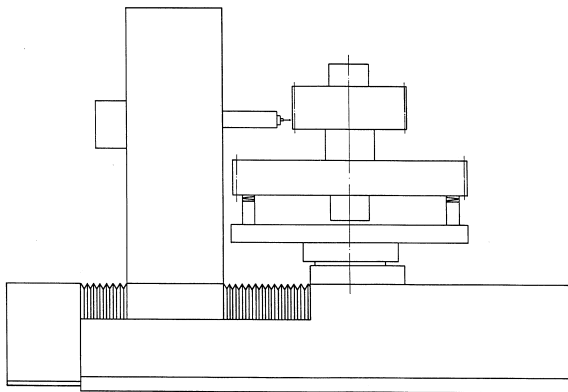


Figure 05: Inspecting a drive shaft with two gears

Instead of the upper tailstock, channeled bearings or fixed stays are also sometimes used, if the clamping range of the column is not adequate for the workpiece to be inspected.

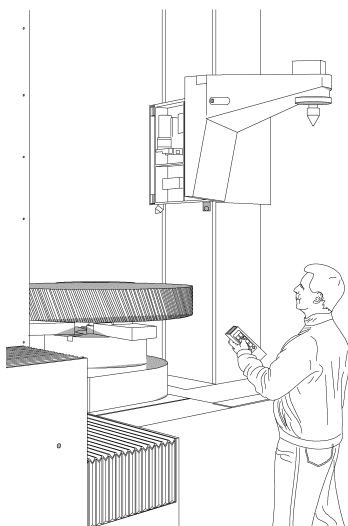


Figure 06: Upper tailstock, mechanically positionable and hinged with remote control

The probe system provided is of particular importance on a gear inspection machine. According to Figure 3, this system is located at the front end of the Y-axis. Three-dimensional probe systems, as shown in Figure 7, provide better prerequisites for recording very different functional surfaces on gear-related workpieces in a single run.

Measured values, as in the case of profile and lead measurement, are recorded on cylindrical gears by using the X measuring axis of the probe system. For lead measurement on cylindrical gears with a large helix angle, or for cylindrical worms, the probing direction can be preselected in the X and Z plane in directional reference to the measuring point. This probing method ensures a high probing accuracy. The Y-probing direction enables e.g. root and tip circle diameters to be recorded on cylindrical gears, as

well as e.g. defined reference surfaces to determine the precise workpiece position.

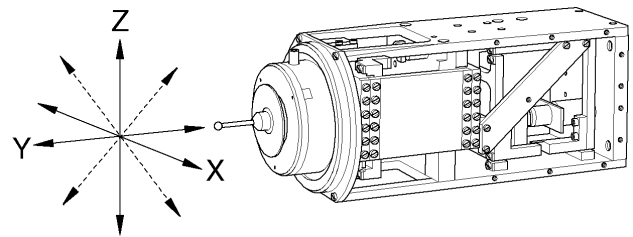


Figure 07: 3D-probe system

In contrast to switching 3D-probe systems, which are particularly suitable for individual point probing, “measuring probe systems” are required for gear inspection for continuous measured value recording (scanning) e.g. in the case of profile and lead measurements. I.e. each measuring axis must have a large measuring path (e.g. 1 mm) and be equipped with an appropriate length measuring system.

In this regard a digital measuring system offers the advantage that the signals can be processed directly in the CNC control without conversion and the measuring accuracy remains constant, irrespective of the measuring path.

Another essential feature of a modern probe system is a probe element exchange device (Figure 8). Here the probe element is connected to a change plate. The connection to the actual probe system is provided by an adapter device with high centering accuracy. A similar device offers the advantage of probe element exchange without recalibration, as the calibration data already stored in the computer system of the inspection machine can be used.

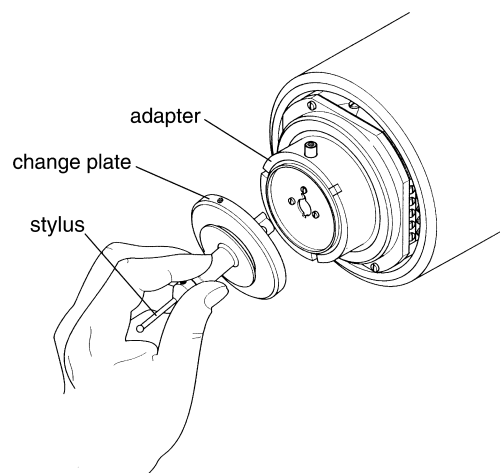


Figure 08: Measuring probe changing device

Also important are the protection systems in a probe system in the event of collision. These prevent downtimes of the entire device, as well as high repair costs.

When inspecting large gears, extended probe rods may be required to cover the entire gear. A typical

example of this is the inspection of large internal gears (Figure 9) for wind power gears. In the example, gear widths up to 500 mm are measured in conjunction with a special probe arm made of carbon fiber-reinforced plastic.

In this case, the probe system must have the necessary load capacity and stability, and accept appropriate probe elements without affecting the measured value recordings.

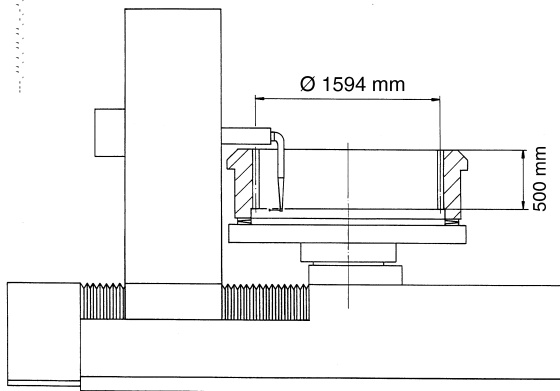


Figure 09: Inspecting a large internal gear

2.2 Control and computer system

In addition to the mechanical components of an inspection machine, the control and computer system form the second essential component.

The CNC-measuring control performs all the inspection machine functions that are important for a measuring run. The schematic design of a control computer unit can be seen in Figure 10. Here the core elements are a rapid 4-axes motion controller equipped with microprocessors with a high clock frequency as well as a higher-level control computer for multiple axes interpolation and measured value recording. In conjunction with special control software, up to 4 measuring axes (X, Y, Z and C) can be linked together. The coupling can occur linearly or for any spatial curves in accordance with predetermined nominal data.

Further processing of measured values occurs in an evaluation computer, a standard commercial PC computer in a current design. The conception of the measuring movement generation and of the formation of measured values via the CNC control, on the one hand, and the presetting of the measuring run and processing of the measured values via PC computer on the other hand, guarantee high system reliability. To further increase availability, the control unit can also be equipped with a modem system. This allows remote diagnosis/remote update of evaluation software and control software.

The standard PC computer system also opens up diverse options for data storage and documentation of measuring results via printer systems.

The interfaces between the inspection machine and the operator are formed by the evaluation computer, including software, for checking the individual gear-related workpieces or gear cutting tools.

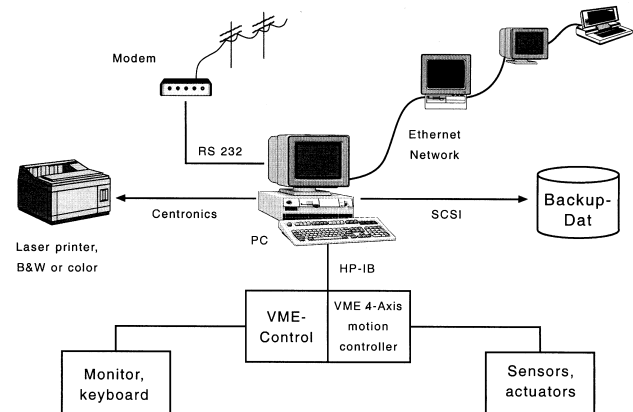


Figure 10: CNC control concept

3.0 Preparation and performance of a cylindrical gear measurement

The operator guidance for the programs should be designed so that the required measuring run can be programmed in plain text without special programming language. Graphically supported operator guidance offers further advantages. When programming a run, all necessary entries/specifications are made, such as:

- Record data for the measurement - such as place of measurement, name of the operator, order no. etc.
- Gear data of the workpiece - such as module, number of teeth, pressure angle, helix angle etc.
- Type of evaluation - such as DIN / AGMA / ISO evaluation, tip relief, root relief etc.
- Measuring run selection - such as profile measurement, lead measurement, gear pitch etc.
- Selection of the diagram magnifications etc.

When programming is completed, the measuring run is stored in the computer under a workpiece identification number. In the case of repeat measurements, this run can be directly reactivated via a catalog of stored runs. A program change is thus possible within a few seconds.

The measuring run itself then proceeds automatically. If desired, a special probing routine also makes it possible to find a tooth gap automatically, provided that you do not wish to probe a precisely predefined tooth flank at first.

When inspecting large and heavy workpieces, before starting the measurement there is the problem of aligning the workpiece with the C-machine axis. In conjunction with a special rotary table with built-in air bearing, even heavy workpieces can be aligned easily and quickly to run concentrically (Figure 11). Any