Mechanics and Electronics: a winning combination

In this article, we will illustrate certain control equipment where mechanics combined with electronics and specific software, offer new means for gear production technology and the mechanical industry in general.

Everyone knows that most common electronic devices have short life spans. Computers and accessories, cell phones, digital cameras, etc. are obsolete within a few months or maximum one year.
New breakthroughs for processors, memories and software follow one another at a spiralling rate, making it difficult to stay updated. The latest PC model today will inevitably be next month's second latest model.
This race, somewhat not as frenetic, affects the industrial sector as well, i.e. machine tools and control equipment.
Updating of electronics and software for numerical controls is quite frequent and the linear motors and so called "direct drives", i.e. motors integral with mandrels that must be set into motion, gain ground.
Now, the "in process" or "post process" controls are expanding.
The first are systems that measure a part as it is being constructed with feedback to CNC regarding part dimensions.
A typical case, very popular for many years, is a check of the outer diameter during the grinding operation. When the diameter reaches the required value, the control system informs the CNC which interrupts the operation.
On the other hand, the "post process" system checks the part as soon as it's finished, several times outside of the machine tool, but also frequently before it leaves the work area.
If the part is outside of measurement specifications, and it is too late for corrections, it will be rejected; only the next part can be corrected through a manual or automatic operation on the machine via specifically provided signals that the measuring equipment transmits to the CNC.
The "post process" control is much needed to identify the drift of a certain dimension i.e. the progressive deviation of a dimension with respect to the initial value; deviation due to tool degradation or progressive thermal settling of the machine tool, or other reasons.
The control of diameters, lengths, grooves or shim positions is common practice, but it is much more difficult when measurements are more complex as parameter detection relating to gear teeth i.e. tooth thickness (or OBD), eccentricity, pitch irregularities, etc… not to mention profile and helical control.
It is evident that all gear dimensions can be measured in a metrology lab, but although this being to the letter, a "post process" control, it is not one normally intended with this expression.
To be effective, a "post process" control must be performed immediately after production of a part, in a short period, possibly inferior with respect to machine cycle time in order to allow the possibility to modify the dimensional error already for the next part without machine stoppage.
It is clear that a timely control check is essential.
As an example, for the past years, gear grinding machines are usually equipped with a profile control system, helix and indexing control system.
It is normally a Renishaw head that was assembled in the machine when the control was needed, but now it is mounted inside the working area.

The control is performed by points inspecting all the profile length and toothed band and also controlling the angular position of all the teeth by using the movements given by the CN axis of the machine.
This system has the disadvantage to require a lot of time and to operate with the machine switched off and does not solve properly the problem.
Recently a new equipment for "*post process*" OBD (Over Ball Diameter) control has been marketed. i.e. the measurement on the tooting rollers equivalent to teeth chordal thickness with possibility to determine the gear radial run out.
The manufacturer of this equipment is the company Metrel located in Cornate d'Adda (Milan) Italy, specialized in the design and construction of special control equipment.

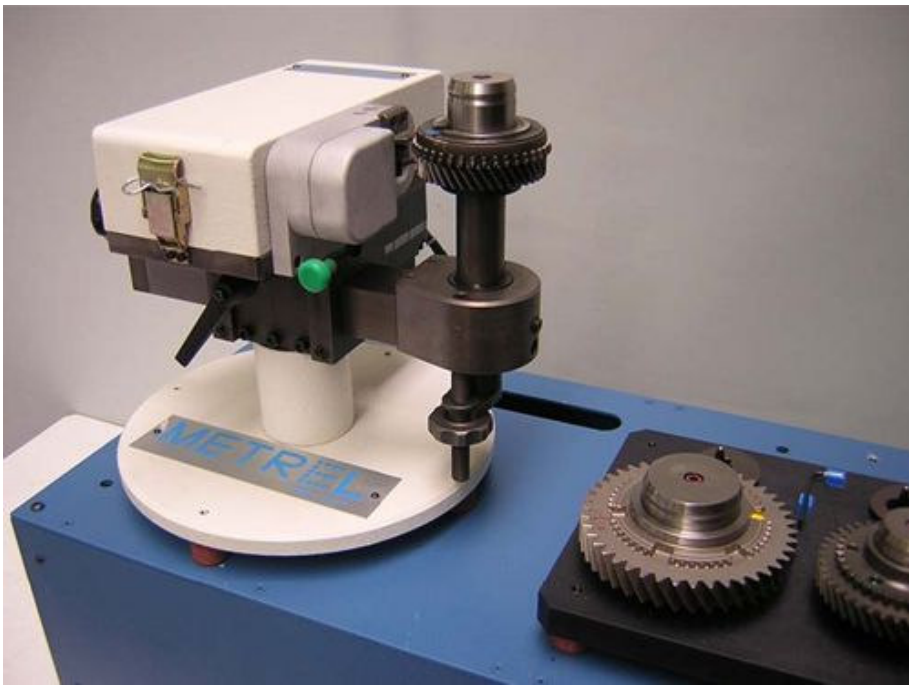

Fig. No. 1- *Equipment for control of OBD dimension*

We describe in short this new equipment that is considered as a valid support in the gears production lines, so that some big automotive companies are equipped with the same for control in mass-production.
The equipment called *"Flexible control for gears"* measures automatically, further to OBD, the F_r'' radial run out according to the standard ISO 1328-2, the value of bore diameter and its out-of-round.
These parameters, are obtained by processing the radial value measured with the ball with respect to the part axis detected by two electronic transducers.
All this is possible on gears with straight or helical teeth with a diameter range from 20 to 200 mm.
Once the part is placed on the special provided mandrel, in manual or mechanical mode, the control is performed automatically by inspecting all the teeth with a speed of about 0,5 seconds/tooth.
The fixture can be equipped by different electronic modules depending on the complexity of the required processing.

The collected data are immediately processed and displayed on the monitor as list or diagrams (Cartesian, polar, histograms etc.), by pointing out eventual errors bigger than the prescribed tolerance.
There is also the possibility to process statistical data to check the accuracy run on a lot of any parts number.

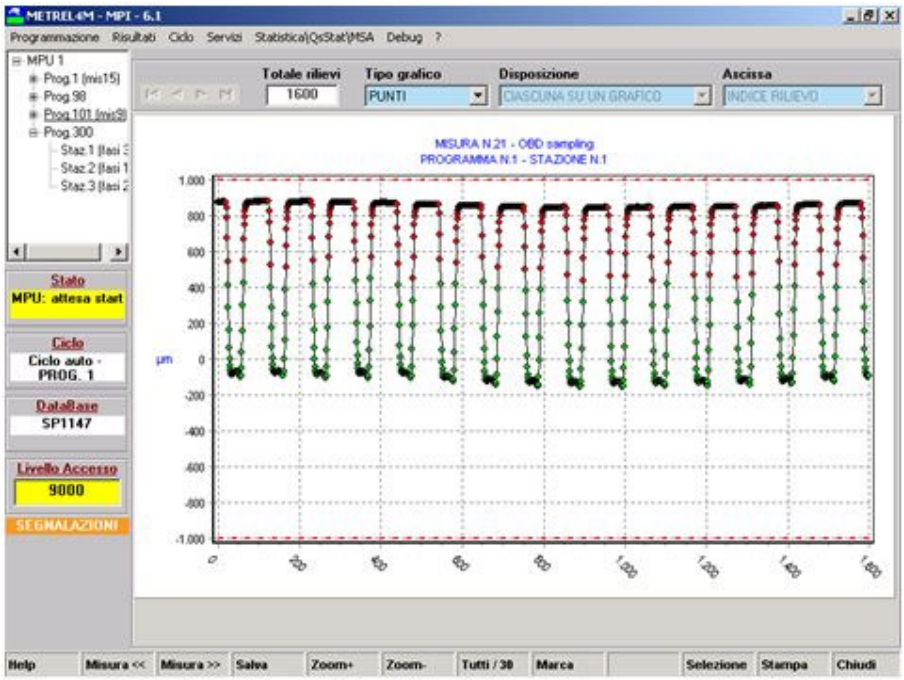

Fig. N°2 – *Example of diagram displayed on the monitor*

As far as the control repeatability is concerned, we can assert that the scattering is really minimum. On the control of the tooting of an input shaft we have obtained a scattering of $2\sigma = \pm 0{,}4\mu$ (67% of the measures) and of $4\sigma = \pm 0{,}8\mu$ (95% of the measures).
The equipment consists of a base module that can be implemented of other additional control devices, in case of need, as the control of diameter centring hole, ovality, taper etc.), the control of synchronizing gear cone, diameters and position of collars and grooves, etc.
Actually Metrel is developing a similar equipment for control of tooth profile and helix in a time that can be compared with the working cycle you want to check.
Of course this is not a measure that can be compared with specialized equipment as Klingelnberg type, but is useful to check if there are profile and helix significant changes during production.
If we think about the shaving operation where the tooth profile must be kept within a defined interval from the first part to last one before re-sharpen the shaving cutter and if we consider that due to wear that forms on the sharp edges, the profile itself tends to approach to the tolerance interval limit. To keep watch this “drift” constantly or frequently and automatically is an important aid for the production technicians.
The construction of these equipment and their components requires a high technology for mechanics, electronic part and software.
Metrel is specialized in the design and construction of special equipment for control of mechanical parts of any kind and in particular all motor components, gearbox components and differential gears (cars, motorcycles, industrial vehicles, etc.).

In addition Metrel manufactures and markets standard components as transducers, plugs and forks for control of inside and outside diameter, loading cells, etc.
Some examples can be useful to understand the sophistication of mechanical- and electronic parts designed and constructed inside the company.

The transducers are devices that are able to signal position changes also in a fraction of micrometer.
The part contacting the surface to be measured is normally a small ball or a part of it connected to a stem that moves a magnetic material pin inside a double induction coil (LVDT system – 2 wires).
The minimum position change of the pin inside the coil generates a voltage that duly treated gives the measure of the inspected surface both if it is a plane, a diameter or any curve.
Small plugs have been manufactured that could measure inside diameters of only two milli meters with a series of four transducers.
The *Nano Leva* is a transducer that represents the mechanical accuracy and electronic resolution.
This HBT (half-bridge) contact type transducer is the smallest of its kind constructed by Metrel and is applied in all measuring equipment where a solid but rugged transducer is required.
NanoLeva is the smallest transducer that can be found on sale and is characterized by the reduced dimensions and solid structure (see figure No. 3).

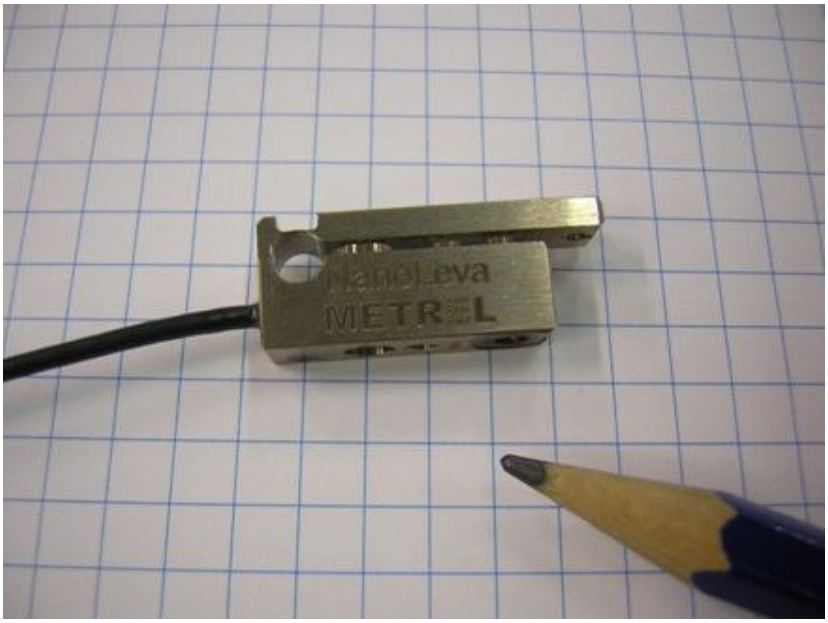

Figure No. 3- *Small transducer called NanoLeva*

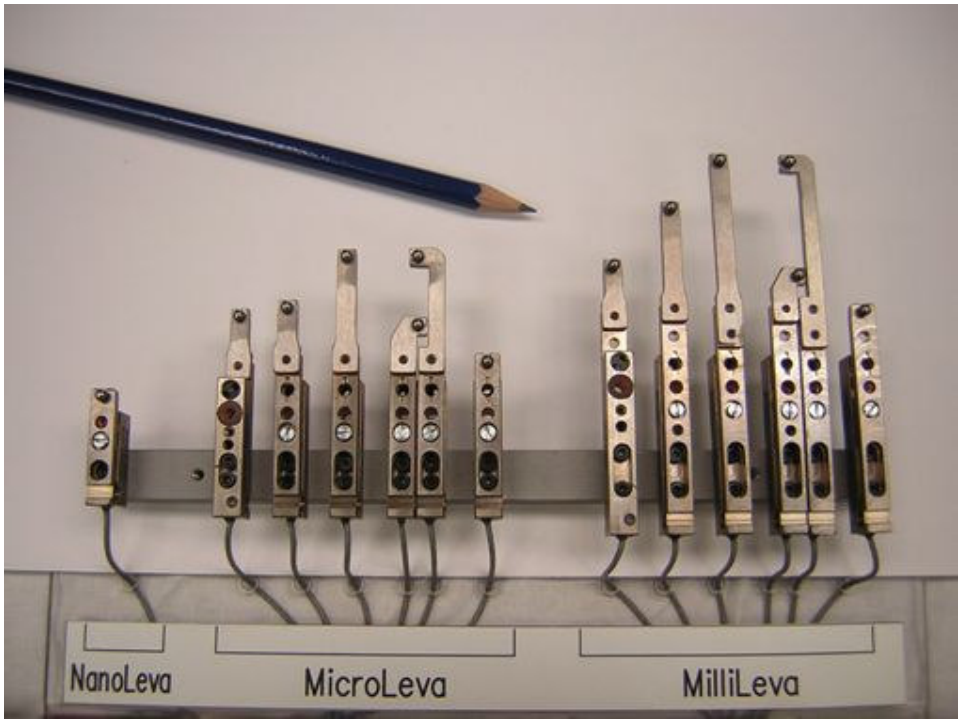

Figure No. 4- *Selection of different transducers types*

Similar to this transducer there is another one which is slowly bigger and is called $\mu Leva$ and another one, called MilliLeva, with bigger dimensions. In figure no. 4 is represented a collection of these transducers where you can see the real dimensions and have an idea of mechanic and electronics problems that must be passed to manufacture these objects.
These features are the result of an accurate design considering the know-how acquired by Metrel in the realization of gauges and measuring equipment for use in production. The high accuracy joint to a sufficient measuring range for a lot of applications, allow to use it in equipment and gauges for control of mechanical parts both for static and dynamic (in rotation) measurements.
The reduced measuring pressure is one of the features that allow to use NanoLeva also on parts with a not high surface hardness.

Mechanic features		*Electric features*	
Linear meas. Stroke around zero	$\pm$ *0,35 mm*	Voltage	$3 \div 6V$
Range for tip adjustment (ball tip diam. 3,175 mm.)	$\pm$ *1,5 mm*	Frequence range	$13 \div 18KHz$
Outward travel from zero	*- 0,5 mm*	Absorption at 10 KHz	*0,3 mA/V*
Inward travel from zero	*+ 0,6 mm*	Calibration voltage	*6 V*
Adjustable zero position	*No*	Calibration frequency	*15,625 KHz*
Repeatability (sigma)	$\sigma < 0,2\mu m$	Resolution	*Analogue*
Spring force	*50 gr.*	Thermal Coefficient	$0,15\mu m/°C$
Linearity (within the measuring range)	*<1%*	Connecting cable length	*2,5 m*

The automatic equipment for control of all worked parts of cylinder heads can be considered as an example of mechanic and electronic complexity. The control is

composed by measuring heads housing over 100 transducers that inspect at the same time the part and transmit signals to an electronic equipment for the processing.
The rolling gear tester is the most common control solution for a workshop that manufactures transmissions. We'll describe more deeply this equipment that in one single control can detect a series of errors on the tooting and on gear body thanks to the combination of precision mechanics and electronics

The rolling gear tester at zero clearance
The rolling gear tester is a control equipment that, through the rotation of the gear to be measured coupled with the gear master, allows to detect some errors on the gear.
100% series production can be checked with the gear testers that allow a functional check, so called because it reproduces the gears use conditions.
Since there are many different gear types which must be controlled and there are different requirements to be met by the gear tester and many ways to use them, the class of the instruments will be very wide and the technical characteristics can be completely different between one equipment and the other.
The gear rolling tester at zero clearance is the more used system for control of gears rolling because it offers a series of possibilities that make it an universal method. The described rolling gear testers operate with the principle indicated in figure No. 5.

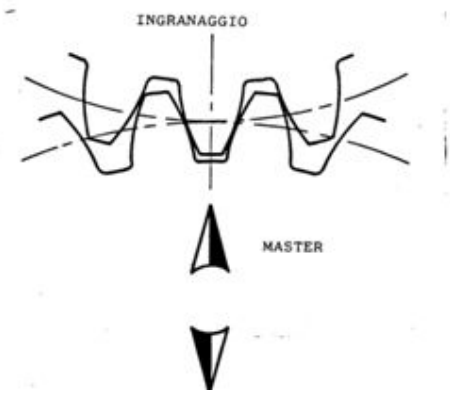

Figure No. 5- *Operating principle of rolling gear tester at zero clearance*

The master gear is pressed against the gear, in this way making contact with both tooth sides, thus leaving no clearance in the mating. The pressure is normally given from one or more springs applied on the carriage on which the master is mounted.
When the gear is set in rotation, the master rotates too and if the mating is faultless, there is no master radial movement. If there are any gear faults or anomalies the master will detect them by moving radial according to the arrow direction as per figure 4.
This type of control can detect following errors :
a) *Centre distance errors*, i.e. tooth thickness errors. Knowing the characteristics of master tooting, the centre axis distance, i.e. the distance between the two rotation axis, is defined only by the dimensions of the gear tooth. We could theoretically know the exact chordal thickness and judge if it lies within the tolerance range. This would result in a centre axis distance absolute measurement. In practice it is preferable to make a centre axis distance comparative control, i.e. the device is set to zero on a given centre axis distance, obtained by a gear master, and measuring the deviations from this value.

b) *Eccentricity errors.* The displacement of the master holding carriage detected during one full turn of the gear. The gear eccentricity is determined from the difference between maximum and minimum displacement.
c) *Nick detection* "nick" means a concentrated tooth deformation on the external diameter or on the side edges and is generated from an accidental impact. This deformation, also if limited, causes an intolerable gear noise during operation. A sudden centre axis distance variation i.e. a quick radial master movement indicates the presence of a nick.

Metrel has set a special master supporting carriage that, added to the previous one, is able to detect also the deviation of helix direction and tooting taper. This is possible since the support of this additional master can swing in two planes: one that intersects to the gear axis and the other tangent to pitch circle, as you can see in the figure No. 6a.

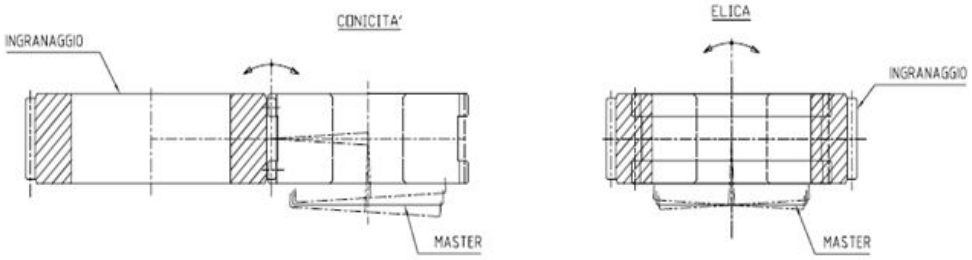

Figure No. 6a- *Diagram of master floating movements for control of helix*

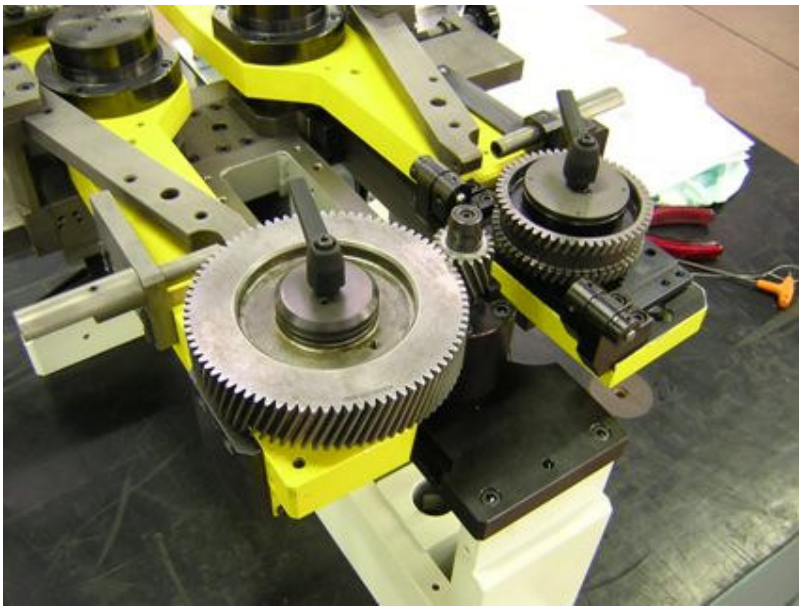

Figure No. 6b- *Application of a carriage and special master for control of helix*

In the figure No.6b we can observe that the master is released at the centre to be in contact with the gear teeth only in the end areas of the toothed band.
The floating in these two directions, detected by special provided transducers, locate a taper error and an helix direction error .
The exam of these two errors, made through a special provided software, allows to determine if the helix error is on the left or right side of the tooting.

A gear tester of this kind can be integrated with a series of sensors that check the geometry of the toothed wheel as : the bore diameter and roundness, verticalness and flatness of the supporting surfaces, the synchronizer taper dimensions or, if we talk about a shaft, we can check, further to different tooting at the same time, also some outside diameters of bearing housing, the position of most important grooves and shims.
Two examples of these controls are represented in the figures No. 7 and No. 8.

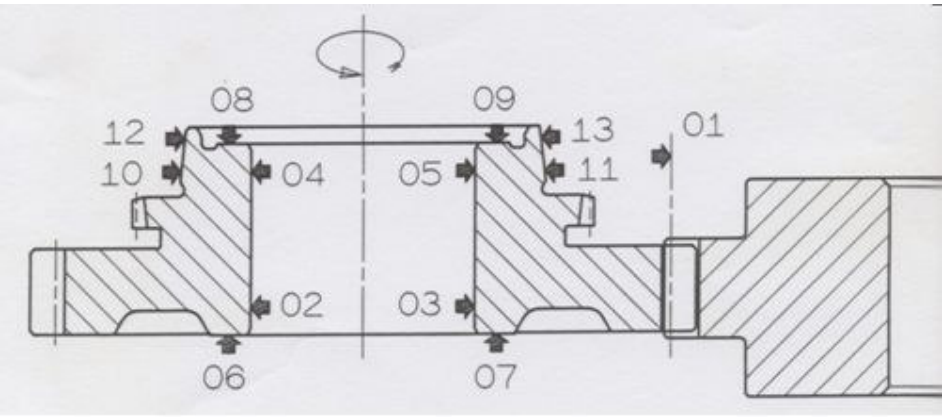

Fig.No.7- *Measuring diagram of a gear with bore*

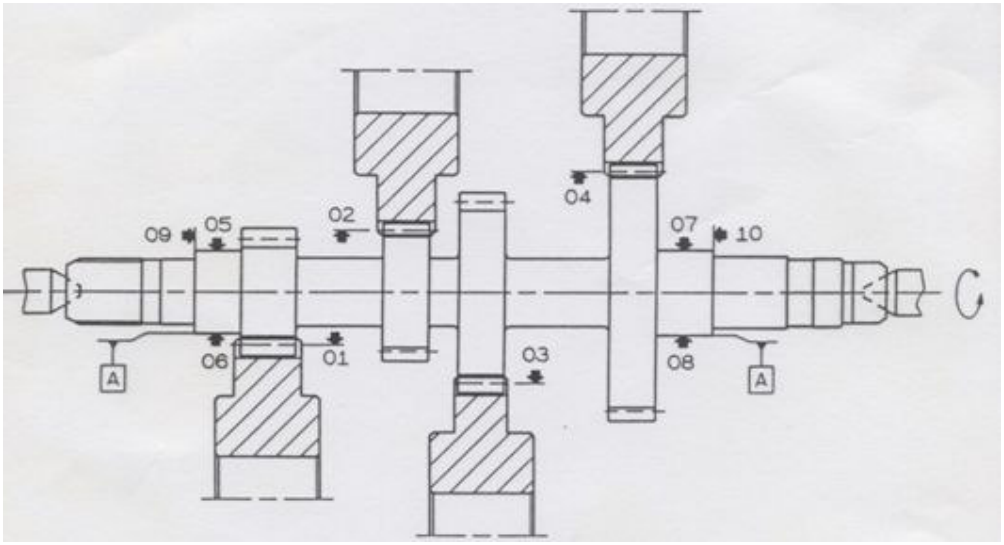

Fig.No.8- *Measuring diagram of a shaft with 4 tooting*.

The equipment for these type of measurements are normally connected to a sophisticated electronic unit that, further to indicate the errors entity can perform any statistical processing type by supplying also the graphic documentation on a parts lot such as errors printout or under statistical graphs form.
The workshop has also to face the eventual recovery of the rejected parts.
If a gear has been rejected because some nicks have been detected on one or more teeth, it can be recovered by removing the dents by means of a high-speed burr. The problem is to locate quickly the dented tooth.
For this purpose we apply in some cases the called marker, that are devices that mark automatically with a paint point the dented tooth.
In the automatic solutions, the parts unloading areas are divided in a certain number of channels where the parts with different error types are unloaded with a first sorting among good parts, recoverable parts and scraps.

M4M Lite electronic Unit

Metrel designs and constructs specific electronic equipment for data collection and processing during any complex control: electronic comparators that signal if the measured dimension is within or out of tolerance limit, very sophisticated equipment as the one described here below that represents the Metrel electronic leading product.

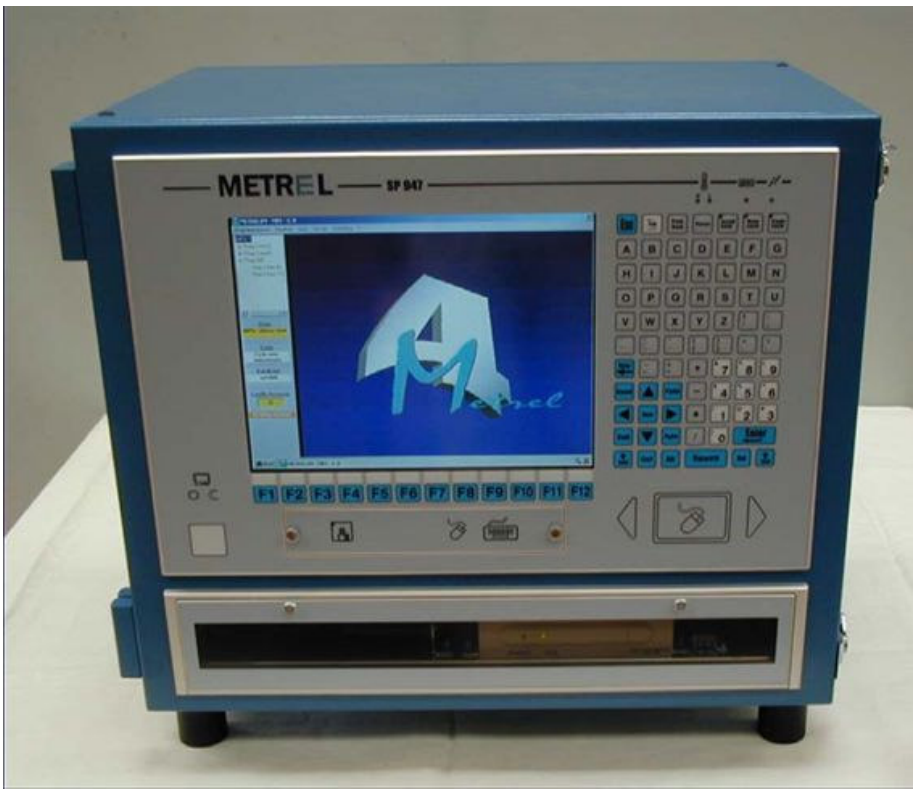

Figure No. 9- *M4M Lite Electronic Unit*

M4M Lite is a complete gauging system designed for dimensional control applications in workshop environment. It is a multi-gauging, multi-program and multi-station system allowing the execution of a high number of programs and measurements. The expansible industrial PC with operating system based on Windows and TCP/IP offers ease of use and integration with different systems. The main performances include : on line statistic (data files that can be stored in qs-stat compatible format), possibility of connection to plant network, multi-language, video guide. The system can compensate the measurements in temperature, in real time, considering the part-, master and gauge temperatures.

Such features together with an accurate hardware planning allow its use both on gauges, manual equipment and semiautomatic benches or in applications on automatic lines.

The system M4M Lite is composed by two hardware components: SP947 (industrial PC) and SP1014 (real time unit) and a Windows 32 Bit Native software, organized in different modules.

The system is housed in a single container with IP65 protection, inside the same there is an UPS device, on option Masterizator or CD-ROM reader for back-up and storage of data and programs or a keyboard with integrated mouse.

With this electronic equipment we can generate statistical files that can be imported from QS-Stat and Excel and control charts and statistic format that can be set per program: X-R, X-MR, MX-MR, SLT, Pareto, histograms, distribution.

The measuring unit has following features:

- *300 probes/program, 24 measuring probes, 300 measures/program, 300 programs and 30 stations per machine.*
- *Customization of all measuring parameters..*
- *Possibility of analysis in depth of the results of each measure.*

Main features of M4M Lite unit:

Power supply	*115/230 Vac; 50/60 Hz; (absorb. 2,5°/220Vac)*
Processor	*CPU Intel Pentium III™*
Ram memory	*128 Mb DRAM on 128 pin DIMM sockets*
Hard Disk	*EIDE 2,5" Hard Disk 20 Gbyte*
Keyboard	*Membrane front panel (alphanumeric) IP 65*
Floppy Disk	*1,44 Mb 3,5" Floppy Disk driver*
Serial lines	*2 RS232 16C550 UARTs serial ports*
Parallel lines	*1 LPT (ECP EPP SPP) parallel port*
Display	*LCD 800x600 12,1" TFT, high brightness*
Video Controller	*SVGA LDC/CRT with 2 Mbyte VRAM*
Connections	*Connector for PS/2 Mouse and PS/2 Keyboard*
	External Connector for ATAPI (IDE) CD-ROM
	External Connector CRT VGA
	Connection for USB port

We can assert that the close correlation between an accuracy mechanics and an advanced electronic and programming technology allows to supply a new generation of advanced equipment to gear industry and mechanics in general, that successfully solve the most complex measuring problems.

Metrel in short

Metrel started its activity in 1975 in the field of design and construction of electronic measuring equipment for use in industrial environment
Today, after 30 years of research, development and experience in the main industries in the world Metrel has the Know How for the design of its products.
Metrel staff consists of about 50 persons.
All products are developed in its design department and in the electronic department for design of analogue and digital development of firmware and software. All critical operations are made in its plant in Cornate d'Adda (Milan), in the mechanical production department equipe of high precision machines in the electronic- and final assembly and testing department equipped with advanced instrumentation.
The know how and expertise acquired in all techniques involved, makes it possible to solve the problems of the customer by applying the most appropriate mix of mechanical, electronic and software solutions. Its products are exported in different countries as: Italy, Turkey, Poland, Russia, Brazil, Germany, India, Romania, France, China, Austria.

Production in short

- Standard components (electronic units and transducers)
- Plugs and forks for electronic measurements
- Post process with correction feedback to CN
- Electronic benches for interoperational control
- Machines for final sorting
- Manual, semiautomatic and automatic control station for following lines:

- *camshafts*
- *crankshafts*
- *connecting rods*
- *piston pins*
- *pistons*
- *cylinder heads*
- *valves*
- *input and output shafts*
- *gears*
- *sleeves*

- Standard applications for:
  - *Connecting rods final control*
  - *Control of continuo spessori nastri metallici*
  - *Shims sorting*
  - *Control on cylindrical tooting of gears and shafts with reference to the standard ISO 1328-2*

- Main customers:
  - *Fiat Auto (different plants)*
  - *General Motors (Powertrain)*
  - Opel
  - Grob-Werke
  - Dae Woo
  - Iveco
  - Kamaz
  - Maruti-Suzuki
  - **Rico**
  - **Campagnolo**
  - **Fondalmec**
  - **Sata**