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# E-rota
# Process and System for Dimensional Characterization of Tubes

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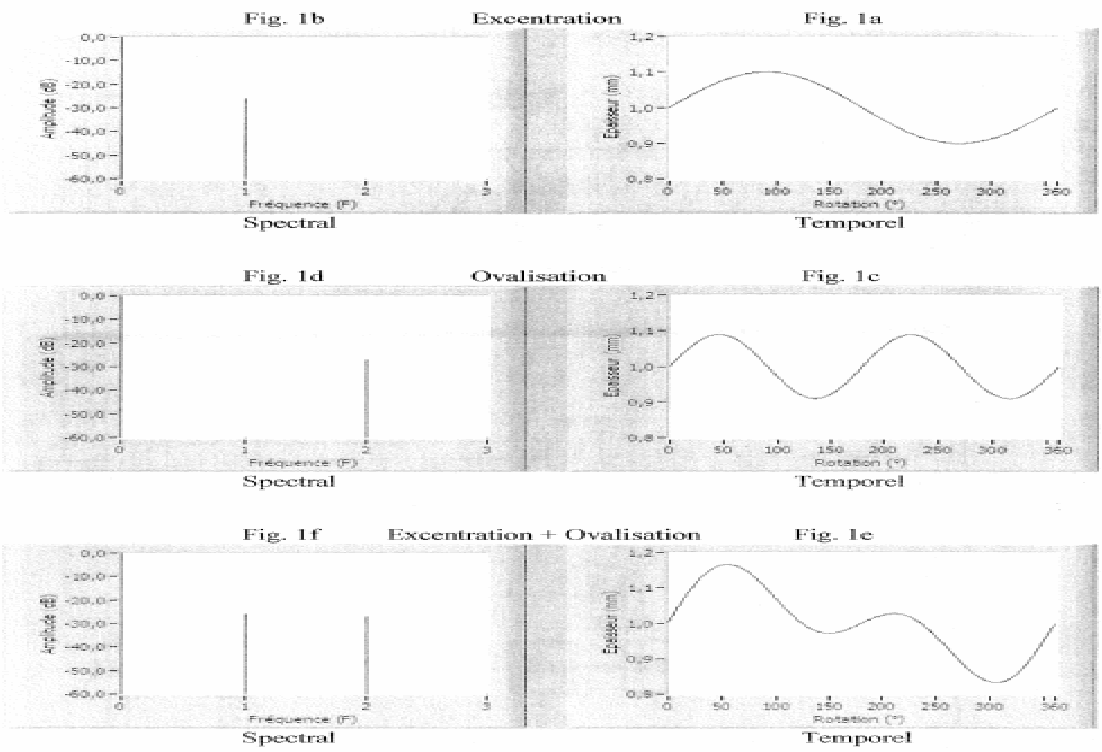
**Abstract**

The process, according to the Patent, aims at the dimensional characterization of tubes and bars at very high speed with extremely simple mechanics, avoiding all rotation either of products or measuring heads. The two data measurements required are the external diameter, as well as the thickness for tube. The principle consists of performing a minimum sampling of measurements evenly distributed in fixed positions around the tube cross section, and to calculate, by interpolation, the real complete curves of external diameter and thickness of this section with the angular resolution related to the requested accuracy on trough and peak amplitudes of those curves. Then we can draw out, with a high reliability and accuracy, the min/max OD and Thickness measurements of each tube. This is repeated at each section of tube running through the measuring head, with the linear resolution requested, realizing thus an in-line testing without any rotation. Starting from this raw data, we are able to calculate all other characteristics of tube such as “internal diameter, eccentricity, ovality, etc…” as with a conventional system using rotation of tube, rotating head, or encircling multi-element probe (phased array).
**Keywords**: UT TUBE DIMENSIONS IN LINE

## Process Description




Analysis of thickness and external diameter curves shows that the profiles of those curves are relatively smooth without any sudden variations. We will focus our analysis on the thickness curve as it is the most complex with two input parameters: eccentricity and ovality. If "F" is the frequency of rotation of tube, an eccentricity alone gives the curve with a thickness frequency variation "F" (sch 1a); but ovality alone gives the curve with a thickness frequency variation "2F" (sch 1c). In case we have both eccentricity and ovality, the final curve is the combination of two frequencies F & 2F with their respective phase (sch 1e).

Let's determine the size of variations with conventional testing systems: the total thickness variation is about max 10% of tube nominal thickness, and the accuracy on min/max of the curve is about 1% of this variation. This leads to a global accuracy of 0.1% regarding nominal thickness, i.e. -60dB.

A spectrum analysis in such condition shows that all frequencies different from F & 2F have always amplitude values lower than -60dB from the continuous level representing the thickness averaging, and therefore they have no interest according to the requested accuracy (sch 1b, 1d, 1f).

Starting from those verifications, the process according to the patent will apply signal sampling technique to tube dimensional measurements. Rather than making multitude of measurements around tube (about 100) to obtain a curve reflecting the thickness variation, as conventional systems do, we will sample this curve in respect of the Nyquist-Shannon theorem, and calculate by the interpolation method, the missing points in order to build the complete curve.

As we have seen before, the maximum useless frequency is 2F which leads us to make, theoretically, at least 4 measurements per section, but practically 6 measurements should be necessary in order to have redundant values allowing a reliable reconstruction of the curve in all cases.

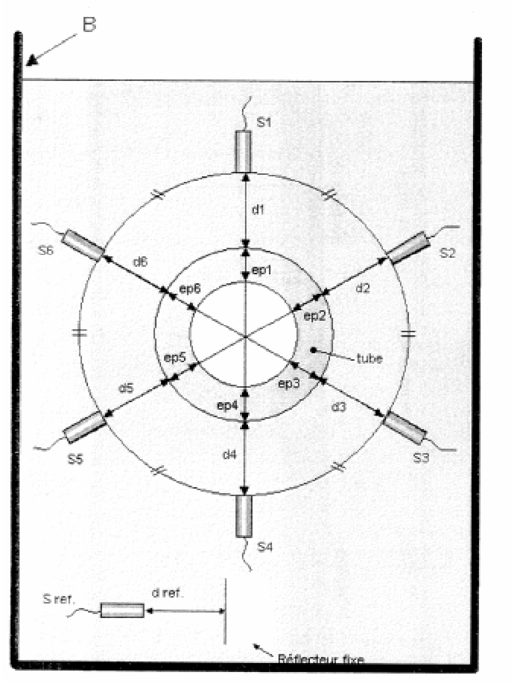



Figure 2a

Transducers are placed around tube at identical angles in order to sample at constant angle, i.e. 60° in case of 6 transducers, with always 2 transducers facing each other for external diameter measurement (sch 2a).

All transducers are fired in a parallel mode per section of tube, increasing the testing speed with a factor of 100 relative to conventional systems that have to make a hundred measurements per revolution to show a correct curve. Nevertheless, such in-line high testing speed is not always necessary, and measurements could be made sequentially between each pair of transducers (facing transducers must fire in parallel).

Before starting the interpolation process, each raw measurement of each transducer can be first processed by a specific in-line Wall thickness program commonly used with Ultrasonic conventional systems applying treatment as follows: aberrant measurement rejection, filtering of important sudden consecutive variations, averaging, etc…

In the example above with 6 measurements in parallel per section of tube, we want to rebuild a curve with 100 points per section in order to have an accuracy of 0.1% of nominal thickness. In such case the interpolation factor is then of 16.

As for conventional systems, the PRF will be 5 kHz; we have then 200µs time to realize interpolation process. In such conditions, this process is fully realizable without any problem thanks to new technologies such as DSP.

This process can be made either in the temporal domain by filtering or in the spectral domain by FFT and inverse FFT.

An advantage has been given to the spectral domain, first because FFT and inverse FFT require less treatment resources when the interpolation factor is high, and then because it allows easy separation of responses due to eccentricity from responses due to ovality, this by suppressing the spectral line corresponding to the phenomenon to eliminate, as we know that those two phenomenon apply respectively to frequencies F and 2F.

This is an important point because we are then able to supply the average thickness (continuous line), the eccentricity (F line) and the ovality (2F line) of a tube section, starting from sampled points, utilising Nyquist-Shannon theorem, and without passing by the interpolated curve, and then without the inverse FFT.

## System Description

- Immersion tank or local immersion box.
- Probe head: most of applications require 6 transducers at 60° around the tube, 12 transducers at 30° are necessary for nuclear tubes. Transducers' position accuracy is not critical.
- One transducer measuring water distance to a reference reflector in order to compensate temperature variations.
- E-rota electronic equipment with up to 16 single channel Ultrasonic PCI cards per industrial PC rack.
- USPC3100LA Ultrasonic PCI cards with real time amplitude and thickness measurements up to 20 KHz PRF. Those cards allow real time data acquisitions with a thickness resolution better than 1µm in steel. Receiver Bandwidth 0.35 – 25MHz allows very thin thickness tube measurements.
- Standard USPC Interface software for USPC3100LA cards calibration and setting, including in-line tube Wall Thickness program. All parameter settings and data measurements are embedded into the PCI card memories in order to insure real time measurements and data acquisitions.
- E-rota software:
    1. System calibration process realized on one tube of production with Thickness and external diameter variations.
    2. Measurement calibration process realized on reference tubes with OD max, Thickness max, OD min and Thickness min.
    3. E-rota processing per section of tube gives in real time: OD, Thickness, ID, eccentricity and ovality.

## E-rota Main Advantages

- High increase of measurement speed
- Cost effective solution as there is no rotation and the number of transducers does not depend on tube diameter.
- All types of tubes, very thick or thin, large or small diameter.
- Very simple probe head; local immersion for large diameter tubes and immersion tank for small diameter tubes.
- Transducers' positioning adjustment on probe head is not critical.
- Thanks to the spectral analysis principle, we can rebuild entirely the exact profile of tube for each section, and, thanks to the high PRF, for the complete tube as well.

- E-rota system can be easily adapted for use on existing linear testing benches currently using rotating heads, encircling EC probes, phased array multi-element probes, etc…