PROBLEMS IN ULTRASONIC TESTING OF FORGED ROTOR PIECES

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This report discusses the basic types of defects in forged pieces for rotors of rotating machines. The physical basis is described as well as the possibilities for using ultrasonic in the defectoscopy of such pieces, as well as the methodological foundation of two basic test concepts. The treatment and analysis of results in the domain of interpretation of the physical characteristics of the defects show the directions for further analyses from the standpoint of service reliability and fracture mechanics.

INTRODUCTION

Physical foundation for testing. Ultrasonic testing is based on the controlled and directed introduction of mechanical energy in the form of waves of ultrasonic frequencies (>20 kHz). The interaction with the material, namely its shape and structure, gives rise to a change of the standard characteristics of the ultrasonic field. By analyzing the nature and the intensity of the change, limits are obtained which define the state of the material. In materials, the following phenomena influencing the propagation of ultrasonic waves can occur:

a1) reflection without change of wave shape;
a2) reflection with change of wave shape;
b) defraction;
c) dispersion with attenuation.

All the above phenomena have their analogs in optical waves and conform to similar laws. From these phenomena, two basic methods for testing have been developed:

I) PULSE - ECHO method, based primarily on reflection and dispersion with corresponding attenuation.

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II) INTENSITY METHOD, based primarily on attenuation and defraction.

Characteristic of the ultrasonic wave and probes. Ultrasonic waves propagate in the form of spherical waves from the source (point of introduction into the material or the point of reflection), the intensity (pressure energy) being maximum in the direction of the axis of propagation. There are two main forms of wave propagation: longitudinal and transversal. In general, they appear separately or, under certain conditions, both types of wave movement can arise simultaneously. Wave propagation follows the law of propagation expressed as:

$$L = c/f \qquad (1)$$

where L is the wave length, c is the speed of wave propagation in the material and f is the frequency of the wave propagation.
In steel materials, speeds vary in a narrow range, so that the average speed is: for longitudinal waves 5920 m/s and for transversal waves 3250 m/s. For certain frequencies used in testing steel, the values are presented in Table 1.

TABLE 1. Change of the wave lenght with different types of propagation

Type of propagation	Speed (m/s)	Wavelength (mm) 1MHz	2MHz	4MHz	10MHz
Longitudinal	5920	5.93	2.97	1.48	0.59
Transversal	3250	3.25	1.62	0.81	0.32

Keeping in mind that it is not possible to completely filter out the frequency, we can expect to discover defects in the material of the order of 0.3 to 0.5 of the wavelength.
The choice of the test frequency (and therefore the sensitivity of the test system) depends on several physical and technical factors, but primarily on the grain size of the material and of the dimensions of the tested piece.
Constructively, there are two basic types of ultrasonic probes:

a) Normal probes (and limited angle probes) with a longitudinal field.
b) Angle probes with different angles and a transversal field.

The angle of the probe is chosen on the basis of the geometry of the tested piece. Here, the total volume is tested and the sound is introduced along all the primary directions of defect propagation (Figure 1). Frequency is chosen on the basis of the material grain size and the way in which the material is formed. In this manner, an optimization of the test system is performed, the maximum sensitivity defined and the requirements of the geometry satisfied.

Types of defects and the methodology for the analysis of the defect echo

Classification of defects. Defects are conditionally classified, according to size (keeping in mind the size of the ultrasonic beam at the location of the defect), into two groups and one subgroup:

a) Defects smaller than the ultrasonic beam:
   a1) spotted;
   a2) elongated;
b) Defects larger than the ultrasonic beam .

Defects can be classified according to frequency into three groups:

c) Individual isolated defects
d) Grouped defects.
e) Cluster of defects.

Combinations of groups are always possible. Groups of defects under a) and b) are characterized and identified on the basis of echo-dynamics, while defects from groups c), d) and e) are characterized and identified on the basis of specific echo-grams (Figure 2)

Classification of defects into groups

During testing, the analysis of the echo begins by classifying defects into two of the five groups. The basic criteria for classification are the forms of the echo-dynamics and the characteristic echograms. The classification is performed according to the block diagram presented in Figure 3.

Methodology for the analysis of individual defects

Echograms of individual defects are analyzed by checking the backwall echo. If there is no noticeable deviation of the backwall echo (> 2 dB), defects smaller than the beam are characterized by an equivalent size and location, while defects larger than the beam are characterized by their real dimensions and location.

Methodology for the analysis of grouped defecs and clusters of defects

Grouped defects. On the basis of the analysis of echograms (also keeping in mind the backwall echo), the maximum equivalent size, mean equivalent size, the dimension and the location of the zone and the number of defects are determined. The mean distance of the defects is determined by the counting method, as shown in the Table 2.

Clusters of defects. The analysis of the echograms determines the size and the location of the cluster zone, the maximum equivalent defect size and the mean equivalent defect size. This group of defects is always characterized by dispersion and attenuation which significantly deviates from the norm. By comparing the attenuation at one defect-free location and a location with defects, the attenuation coefficients are determined. The coefficient correction factors are heuristically data obtained through comparative testing of samples by destructive methods (metallography, magnetic particle and liquid penetrant testing), on one side, and ultrasonic testing, on the other. The average distance between defects is determined, as shown in the table 2, by a statistical method. The block diagram of the manner of defect analysis is presented in Fig.3

Determination of defect types

The classical ultrasonic method - i.e. the testing in the time or one dimensional space domain - determines certain geometrical relationships. The method is suitable for the determination of the location of reflection, the determination of relative and absolute size of the reflectors (defects) and, to a certain extent, for determining the shape of the reflectors (volume, plane, irregularities, etc.). The method is not suitable for the determination of the type of defect. Therefore, the type of defect is determined indirectly on the basis of the form of defect, its location and distribution, as well as other available data pertaining mainly to the technology of manufacture.

TABLE 2. The average distance between defects

CHARATERISTICS	GROUP DEFECTS	CLUSTERS OF DEFECTS
Method	AVG\COUNTING	AVG\STATISTICS
Size	Oaks/Oekmax/Zone	Oaks/Oekmax/Zone
Location	Zone	Zone
Dumping	-	a_S, f
Density	$n_V = z/V$	$n_V = f(a_S, S)$
Distance	$l = 1/(n_V)1/3$	$l = 1/(n_V)1/3$

CONCLUSION

Data obtained by ultrasonic testing of pieces permits an estimate of the quality of their manufacture and of the possibility of their reliable operation. Using corresponding norms and standards, or, in specific cases, special methods for the calculation of the parts with defects, it is possible to decide if the parts are acceptable for operation or to calculate their operational life expectancy.

USED SYMBOLS

Oek - equivalent defect size
z - number of defects in beam
V - volume covered by sound in the defect zone
S - area of cluster zone in the plane exposed to sound
a_S - attenuation coefficient
f - attenuation coefficient factor
n_V - defect density
l - average defect distance

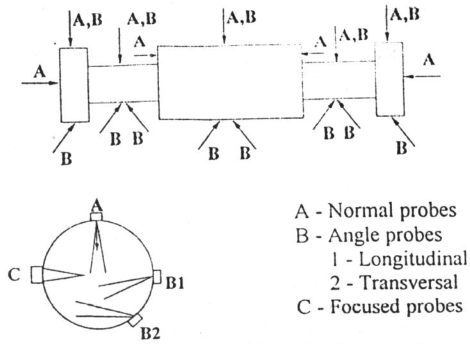

Figure 1. Testing positions with total volume testing

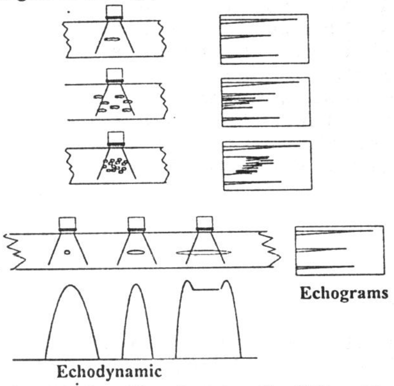

Figure 2. Specific echograms for different types of defects

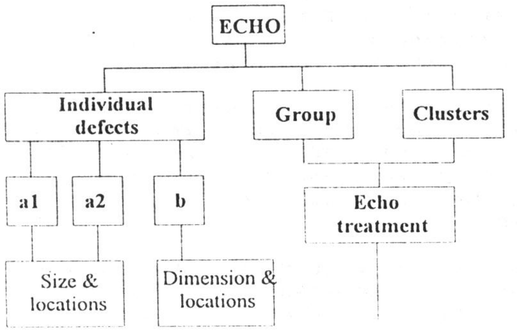

Figure 3. Block diagram of the manner of defect analysis