SYSTEM ANALYSIS FOR WIDE BAND

ULTRASONIC TEST SET-UPS

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INTRODUCTION

In the last years, the discussions about ultrasonic test equipment focussed on amplifier band width and on different types of transmitters, without leading to a clear recommendation. One now tries to reach a better understanding by a system analysis of the test equipment.

As pointed out in Fig. 1., a typical test set-up for a ultrasonic inspection consists of a transmitter which drives the electrical part of the probe. Via the piezoelectric effect, the mechanical part of the probe generates an ultrasonic wave which is reflected by the flaw, received by the probe again and amplified in the receiver. Therefore, the echo displayed on the CRT is affected not only by the type and size of the flaw, as it should be, but also by all non-ideal parts in this transmission chain.

The demand for a successful flaw analysis is that the test equipment produces

- no distortion on the echos
- no noise.

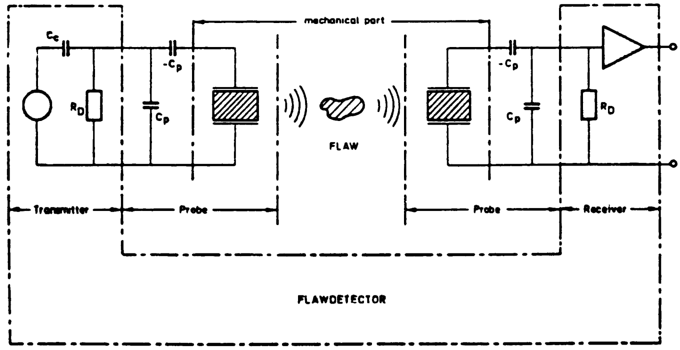

Fig. 1. Schematics of an ultrasonic test set-up.

In the following, we will investigate these demands in three different regions of the test sample: in the middle of the test piece, near the entrance surface and very far away from it. Of course, the first case is the easy one.

NDT far away from any Surface

The most natural transmitter for wide band ultrasonic test equipment is the so-called spike pulser which generates a needle-like electrical pulse for the probe excitation. Such a transmitter has a flat top frequency spectrum, as it is known from its similarity to the δ-function. Of course, this transmitter needs a flat top receiver to achieve a flat top overall frequency response in the test equipment. Principally, there are no limitations to bandwidth, if we exclude the limited bandwidth of the probe.

A second type of transmitter is the so-called step-pulser which excites the probe by a sharp voltage step, as shown in Fig. 2. If this pulse is differentiated, a δ-function is the result. A frequency spectrum as 1/f, where f is the frequency is, therefore, expected. Now, is we need an overall flat top frequency response, a receiver with an "inverse" frequency behaviour, as shown in Fig. 3, is needed to compensate the

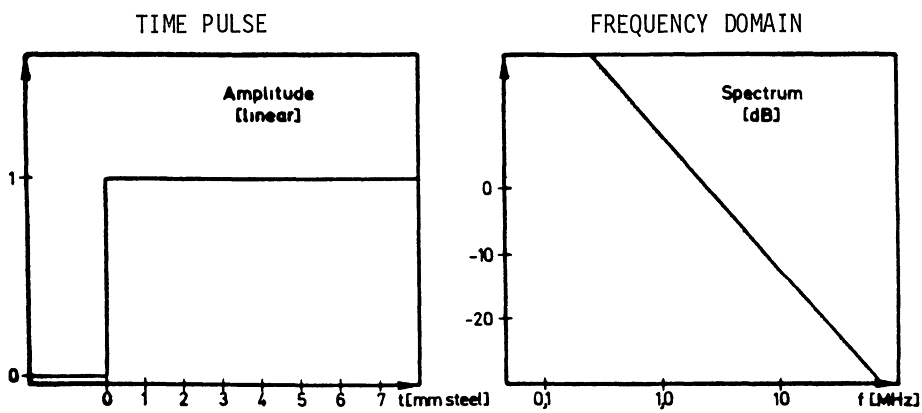

Fig. 2. Step excitation, time and frequency domain.

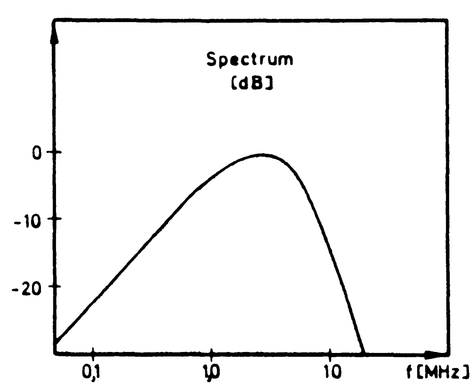

Fig. 3. Inverse receiver for the step-pulser, frequency domain.

response of the transmitter. Again, no band limitations are expected with this concept.

The third type of transmitter which is used, is the so-called square wave pulser. The square wave pulser generates a voltage step and a period T later, a second step to the base line. The frequency spectrum is known as the sinc-function which, at low frequencies, shows a flat response and at higher frequencies a 1/f decay with zeroes (Fig. 4). The corresponding "inverse" amplifier to give a flat overall frequency response, is not easy to design. But both, the flat top amplifier and the amplifier for the step-pulser, give a reasonable bandwidth. The advantage of the step-pulser is the doubled amplitude in the frequency spectrum in a limited region, which gives up to 6 dB gain in the echoes if using band limited probes, compared to the other pulsers. To this point neither the spike-pulser concept nor the step-pulser concept has a measurable advantage when compared. The problem arises from the common practice to misuse a step-pulser for working with needle-pulses. With the help of the damping resistor and the probe capacity (Fig. 1) the step-pulse of the normal transmitter is differentiated, thus having a sharp needle-like transmitter pulse with a flat top frequency spectrum. Now numerous problems arise:

- Since the damping resistor works in the transmitter and in the amplifier input stage simultaneously, not only the 1/f decay is compensated, but an increasing frequency response going with f is effective at lower frequencies (see Fig. 5). The net effect is a limited band width, which depends on the probe and on the flaw detector.

- Each probe has to be tuned individually with the damping resistor to move the flat response of the transmitter on the flat plateau of the probe. As shown in Fig. 6 a distortion in the mean frequency up to a factor of two to lower frequencies is possible in this tuning process.

- The signal-to-noise ratio gets worse. The point at which the signal-to-noise ratio is determined is where the lowest amplitude in the transmission chain is present. This is, of course, the probe output to the amplifier. For a good signal-to-noise ratio,

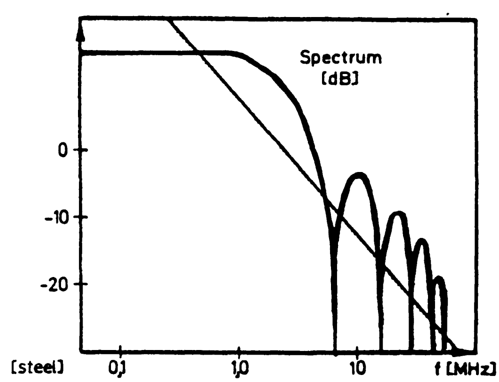

Fig. 4. Frequency spectrum of a square-wave pulser.

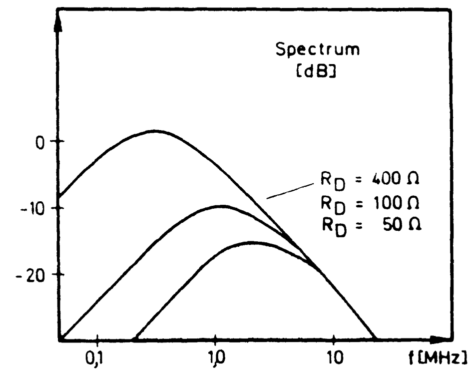

Fig. 5. Frequency spectrum of the spike-pulser for different low cut-off frequencies.

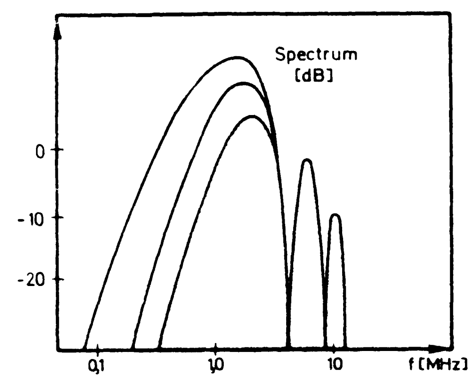

Fig. 6. Convolution of a spike-pulser with a wide band probe, for different damping values.

the amplitude at this point should be as high as possible. All filters should work after this critical point. But, as indicated in Fig. 5, the tuning process with the damping resistor does just the reverse and removes the low frequency part of the spectrum just before this critical point.

A summary for NDT far away from any surface: the step-pulser, together with its inverse amplifier provides the best band width and the best signal-to-noise ratio compared to the square-wave-pulser or to the spike-pulser, when it is the previously mentioned simple type.

NDT near the Entrance Surface

Measuring near the transmitter-pulse or near the interface echo can change the objectives, because resolution problems can lead to distortions of the original echo in the same way as incorrect amplifier passbands. For a systematic investigation of this problem, the effect of the interference of two echos has to be analyzed. As a measure of interference, the following definition seems to be suitable:

$$I(t) = \int_{-\infty}^{+\infty} x_1(\tau - t) \cdot x_2(\tau) d$$

t is the time between the two pulses $x_1(t)$ and $x_2(t)$. (See Fig. 7.) If I(t) is zero, both pulses do not interfere, when their distance in time is t. For simplicity, we assume that $x_1(t) \cdot \alpha = x_2(t)$, meaning that the shape of the interface echo is the same as the shape of the flaw echo beside the amplitude, which is α times higher. Therefore:

$$I(t) = \alpha \cdot \int_{-\infty}^{+\infty} x_1(\tau - t) \cdot x_1(\tau) d\tau = \alpha \cdot \mathrm{ACF}(x_1(t))$$

where AFC(t) is the so-called autocorrelation function of x(t).

All flaw detectors have a transmission band with a low cut-off frequency and a high cut-off frequency. The autocorrelation function of such a limited passband is sketched typically in Fig. 8, for two values of the low cut-off frequency. It shows that the lower cut-off frequency determines the range of the influence zone for very low interference values, whereas the high frequency cut-off determines the amount of interference, when high interference occurs. In other words: if we have

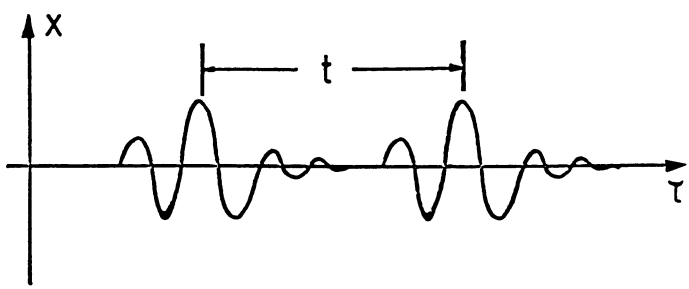

Fig. 7. Interference of two echoes.

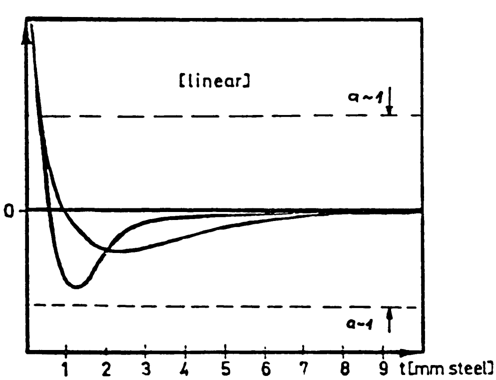

Fig. 8. Autocorrelation function for two passbands with different low cut-off frequencies.

resolution problems with two pulses of almost equal size, that is $\alpha \sim 1$, then the amount of interference is determined down to very low values by the high cut-off frequency. Otherwise, and that is the typical NDT problem, if we have resolution problems with a large pulse like the interface echo, and a small pulse like the flaw echo, it follows that because $\alpha >> 1$ the low cut-off frequency of the passband determines the amount of interference. In this case it is favorable to reduce the band width to lower frequency values for a faster decay of the interference zone (Fig. 9).

The result of this analysis is that near boundaries where resolution problems might distort the flaw echo, the operator has to make a trade-off between band width and resolution. This trade-off depends on the amplitude ratio of the interfering pulses and has to be adjusted individually.

With the spike-pulser concept the control of the lower cut-off frequency is possible to a certain amount with the adjustment of the damping resistor. If the one interfering pulse is the transmitter pulse, the pulse ratio α is simultaneously affected, leading to a saturation effect in the resolution control [1]. As said before, the mean frequency will be shifted in this tuning process simultaneously. Due to a decrease in the echo amplitude, the S/N ratio will become worse.

With the step-pulser concept the control of the lower cut-off frequency is possible through the damping resistor. Neither the mean frequency nor the pulse ratio "α" in the interference function is affected. The low cut-off frequency can be fully controlled (Fig. 10).

The same applies to the square-wave-pulser which needs an additional control, for example an adjustable damping resistor, to control the low cut-off frequency.

NDT at Large Distances

At large distances the echo amplitude will decrease, due diffraction and attenuation. In this case, there is no means to enhance the S/N ratio, if a spike-pulser or step-pulser concept is used, but the increase of the transmitter pulse. This square-wave-pulser, or, better a "burst"-pulser, at this point offers the possibility to increase the amplitude by a multi-excitation.

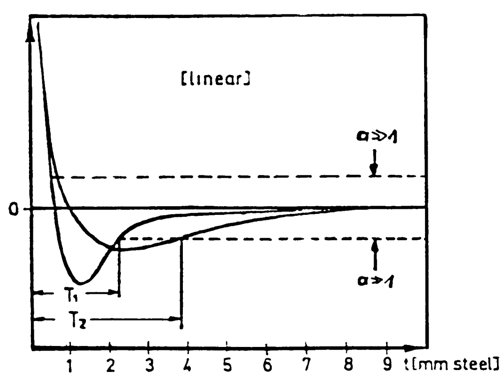

Fig. 9. Interference zone for two low cut-off frequencies.

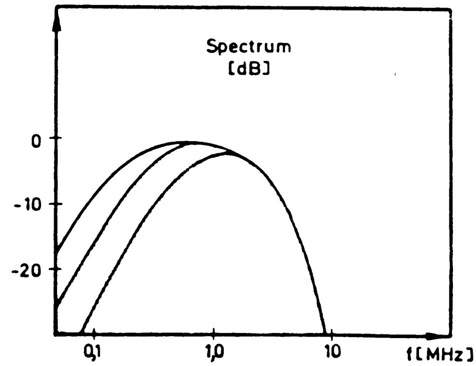

Fig. 10. Band width control with the step-pulser concept.

The only problem is that this principle of multi-excitation only works with probes of high Q, because the gain in power is proportional to Q or, in other words: the band width must be limited.

SUMMARY

We can summarize as follows: under equal measuring conditions, and using an appropriate transmitter concept, the usable band width in NDT with ultrasound depends only on the existing noise, either statistical noise or interfering echoes. For most applications the step-pulser with an inverse amplifier has the most favorable features.

REFERENCE

1. U. Opara, H. Jacobs, H. Schlemm, "Optimized Frequency Response in Instruments", 10th World Conference on Non-destructive Testing, Moscow, 1982.

DISCUSSION

From the Floor: I'm curious, are you covering these sorts of systems now with different options pulsers?

U. Opara: Yes, we now normally offer the step-pulser concept in our top instruments. In the USD1, either a step-pulser or a square-wave-pulser may be selected.