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RESEARCH AND DEVELOPMENT OF HIGH TENACITY FIBERS

PART III

DETERMINATION OF IMPORTANT PHYSICAL PROPERTIES OF FIBERS FOR BALLISTIC ARMOUR

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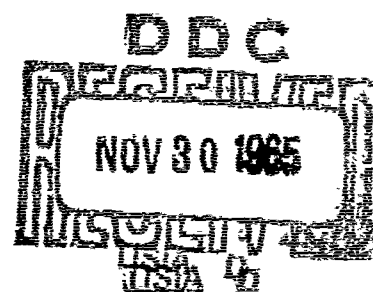
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INTRODUCTION

The purpose of this project is to search for the physical properties of a fiber which are important in determining its ability to resist penetration by a metallic fragment when woven into ballistic armour. Presumably if these properties were known, fibers could be tailored to give maximum resistance.

The method of attack it is proposed to use is one that presupposes nothing. A considerable number of physical properties will be measured. When information becomes available from the Naval Research Laboratory as to the capability of resistance of all fibers measured and submitted for evaluation, a multiple correlation will be carried out to determine the relative effect of each property studied on this resistance.

While this procedure is quite common, it is worth a little explanation to make quite clear what kind of information will be obtained.

Suppose a series of n fibers is selected for study and a series of m physical properties are measured on each.

These fibers will then be submitted to ONR for evaluation and it is presumed that this evaluation will produce a numerical value for each fiber which represents its ability to resist penetration by a specific projectile.

This value will be termed a response and denoted by Y .

The different physical properties measured will be denoted by $X_1, X_2, X_3, \dots, X_m$.

It is presumed that a total of n values of Y will be obtained. From this data the following empirical equation can be obtained.

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots + b_mX_m \text{ where the } b\text{'s are constants.}$$

This procedure is without limitation excepting that n must exceed m in order to permit calculation of all the coefficients of the X 's in this equation.

If n is considerably in excess of m an estimate of fit can be obtained from which the statistical significance of the equation coefficients can be computed. This will permit elimination of those which are not significantly correlated with the response. If n and m are nearly equal then each response must be measured at least in duplicate to provide an error estimate from which the significances of the coefficients can be computed.

This procedure is actually a simplification of a more general procedure in which the significance of all possible product terms and all quadratic terms is also computed. To carry out such an analysis requires a very large value of n as compared with m and is presumed to be impossible in this case. The simplification to be used will in general result only in determination of all possible linear correlations, and no curvilinear comparisons.

There are certain modifications of the above-described general procedure which will also be examined. For example, experience has indicated that fiber tenacity is correlated with resistance, within a given type of fiber. Obviously, then, tenacity should be used as a response in a preliminary study to determine whether such a correlation is general. In addition, it is known that for a given material

$$V_c = \left[Me^2/d \right]^{1/2}$$

where V_c = critical velocity

M = sonic modulus

e = elongation at break

d = density

Accordingly, a pseudo-property consisting of the right hand term of the above equation should also be included in the regression analysis.

A different approach will also be tried. This consists in measuring the linear regression of the above right hand term with tenacity and subsequently with the Y value obtained by ONR, then expanding the residuals not explained by this regression into a linear equation in the other physical properties measured.

It is thus evident that considerable choice is available in how the data analysis may be carried out. As many as possible of these ways will be examined, with the ultimate aim of arriving at not only an empirical equation in Y but also an approach to a mathematical model for the underlying causes of resistance.

Whatever the final choice the result will be one or more equations relating the response to the physical properties measured, or to certain combinations of them. From these equations the optimum physical properties for maximum resistance to penetration should result.

Our experience with fibers suggests that it will be most improbable to find a fiber which will be optimum in all properties. Selection of the optimum thus will probably result in choosing the best compromise, for which the magnitudes of the significant coefficients of the final equation is the best guide.

Finally, since such armour must presumably be equally protective over a wide range of temperatures and humidities the selected fiber must be one in which the important physical properties are relatively insensitive to changes in temperature and humidity, and this will have to be examined before the fiber can be considered as worth further study in woven constructions.

CHOICE OF FIBERS TO BE TESTED

It is important to note that the requirement in choice of fibers is to select a group showing as wide a range of physical properties as possible in order to make the developed equation more precise.

With this in mind, the following fibers have been selected.

1. Nylon 66 tire yarn
2. Twisted Nylon 66 tire cord, greige
3. Nylon 66 tire cord, hot-stretched
4. Tempered Nylon 66 tire yarn
5. Tempered Nylon 66 tire cord
6. Dacron tire yarn
7. Glass fiber yarn X994
8. Glass fiber yarn E type
9. Tyrex Rayon tire yarn
10. Orlon
11. Kuralon (polyvinyl alcohol)
12. Polypropylene 12 gpd tenacity
13. Polypropylene .5 gpd tenacity
14. Polyethylene

A twisted nylon tire cord can be stretched 6-7% due to compacting of the fibers, before any stretch of the fibers themselves occur. This compacting is resisted by the inter-fiber friction which is largely determined by the fiber's finish.

Hot stretching causes a considerable degree of compacting.

Tempering causes even tighter compacting and compresses the fibers into hexagonal and pentagonal shapes.

It is thought that inclusion of these twisted cords, together with glass at one end of the extensibility range, and polyethylene at the other should give the wide range of physical properties desired together with sufficient intermediate points to give good precision in the equation constants.

PHYSICAL PROPERTIES TO BE MEASURED

1. Percent crystallinity
2. Mean orientation in degrees
3. Imperfection in crystal structure
4. Creep at room temperature at 10 cps
5. Instron tenacity at two rates of testing
6. Density of fiber
7. Instron elongation at break at two rates
8. Velocity of sound
9. Attenuation of sound wave by fibers.

PROGRESS TO DATE

The early stages of this work were spent in planning, and in putting together the equipment for measurement of sound and its attenuation.

Basically, this procedure involves the use of two piezoelectric transducers of Rochelle Salt, one of which, the driver, introduces a longitudinal sound wave into the fiber, yarn, or cord under investigation, and the other picks it up.

The signal to the driver is obtained from a wide-range oscillator, the signal being so adjusted as to produce a pure sine wave, as measured by an oscilloscope.

Arrangements are made to permit loading the yarn with various loads, and the oscillator permits the use of a wide range of frequencies.

A factorial experiment is now under way to measure the effects of frequency and load in order to select the desired combination to be used in the analysis.

Sound velocity may be measured, either with a digital counter capable of measuring in micro seconds, or by location of the nodes in the standing

wave generated in the yarn as a result of the phase relationships between signal and its reflections.

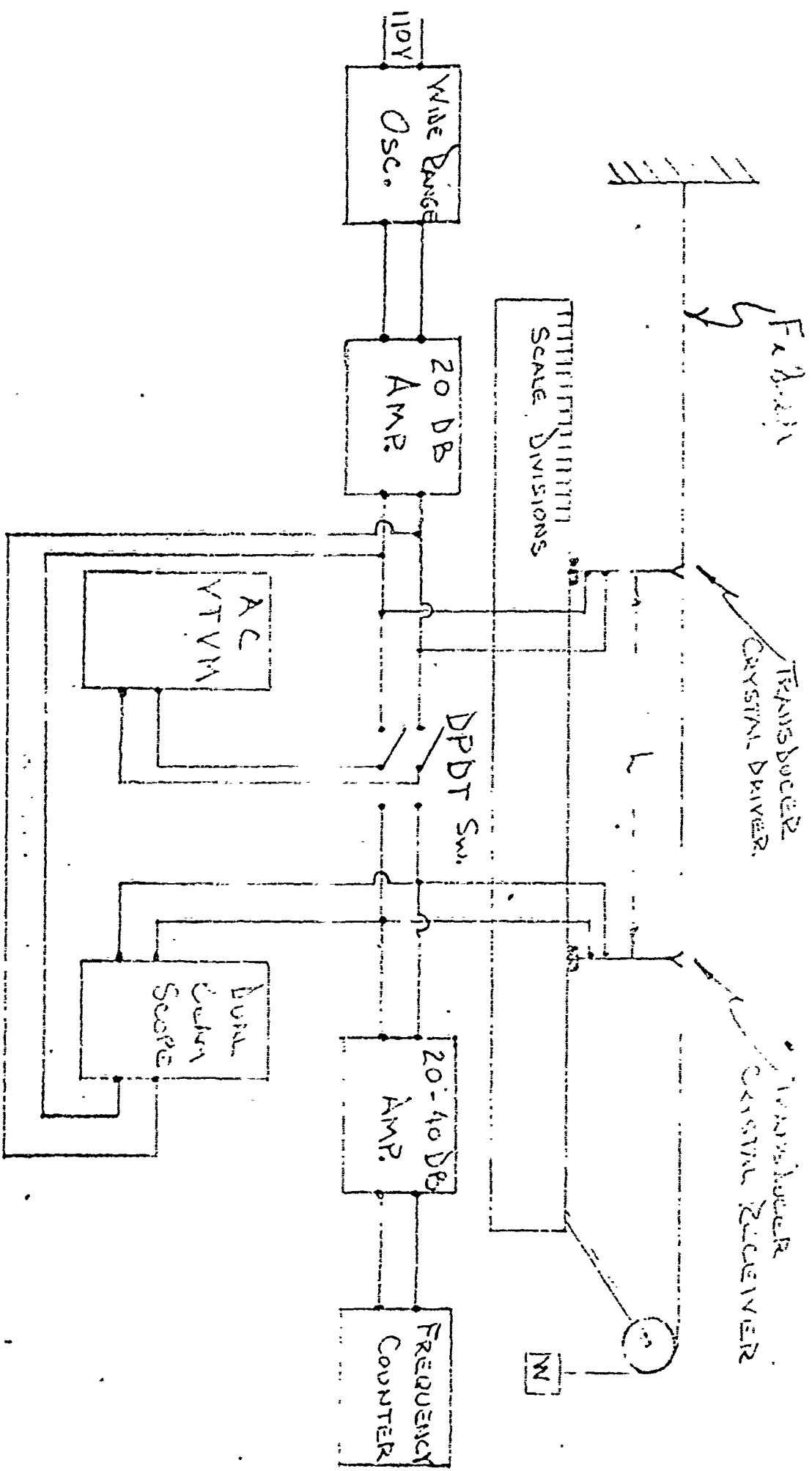
Attenuation is measured by determining the reduction in amplitude of the peaks in the standing wave starting from the driver.

Some measurements have been completed. Insufficient has yet been obtained to be worth reporting.

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MEASUREMENT OF VELOCITY OF SOUND IN FIBERS