Replica Tape:
Linearization of Roughness Measurements

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Background

Many sensors used to measure physical parameters respond in ways that are not directly proportional to the properties they are designed to quantify. Devices for which this is the case are said to be non-linear. Photographic film, certain types of thermometers and chemical detection instruments are examples of sensors that are inherently non-linear.

Digital processors can be used to compensate for non-linear sensor response and are commonly used for this purpose in modern measurement devices.

Replica tape, in wide-spread and long-standing use to assess surface profile in the Coatings and Linings industry, displays a somewhat non-linear replication response to roughness.

This paper describes procedures that can be used to linearize roughness measurements made with replica tape.

Replica Tape

Replica Tape consists of a layer of compressible microfoam coated onto a durable incompressible polyester substrate of uniform thickness. When collapsed against a surface that has been cleaned and roughened by blasting, the foam acquires an impression of the surface "profile", such that the highest peaks on the original surface come to rest against the polyester layer and the deepest valleys are replicated as peaks in the foam. Measuring the thickness of the resulting replica, and subtracting out the thickness of the incompressible substrate, gives a good measure of peak-to-valley height of the profile, a parameter important to determining whether paint will adhere.

The standard mechanism for measuring a replica's thickness is a spring micrometer.

The most commonly used grade, or thickness, of replica tape has the designation "**X-Coarse**". This grade covers, approximately, the range of profile heights extending from 38 um to 115 um (1.5 to 4.5 mils). Because some applications require measurements to lower profiles, a second grade, "**Coarse**" can be used to extend the range downward to 20 um (0.8 mils). Coarse grade covers the range of 20um to 63um (0.8 to 2.5 mils).

Each grade of tape responds non-linearly at the lower end of its range - where the foam becomes fully compressed - and at the upper end of its range - where the peak heights are greater than the foam's thickness.

As the tape's response becomes increasingly non-linear, measurements become increasingly inaccurate. Testex addresses this by setting conservative limits on the tape's useful range. For "**X-Coarse**" this range is 63um to 115um (2.5 to 4.5 mils). For "**Coarse**" the range is 20 to 38 um (0.8 to 1.5 mils). Small inaccuracies appear at the upper (115 um, or 4.5 mils) of "**X-Coarse**" and lower (20 um, or 0.8 mils) end of "**Coarse**". In the overlap region between the two grades an inconvenient averaging procedure must be applied.

Linearization

Use of a thickness gage incorporating a digital processor permits the option of displaying linearized peak-to-valley profile if the replica foam's response function, relating replica thickness to height of the profile, is known.

Suitable "response curves" can be deduced from experiments in which replica tape determinations of profile are plotted against profiles obtained with electronic stylus roughness instruments for many different abrasively-blasted test surfaces. A separate response curve is deduced for each grade, or thickness, of replica tape. In general, stylus measurements display greater statistical noise than replica tape, but have the advantage of better linearity. Linearizing replica tape's response combines the low statistical noise of the replica method with the linear behavior of the stylus method.

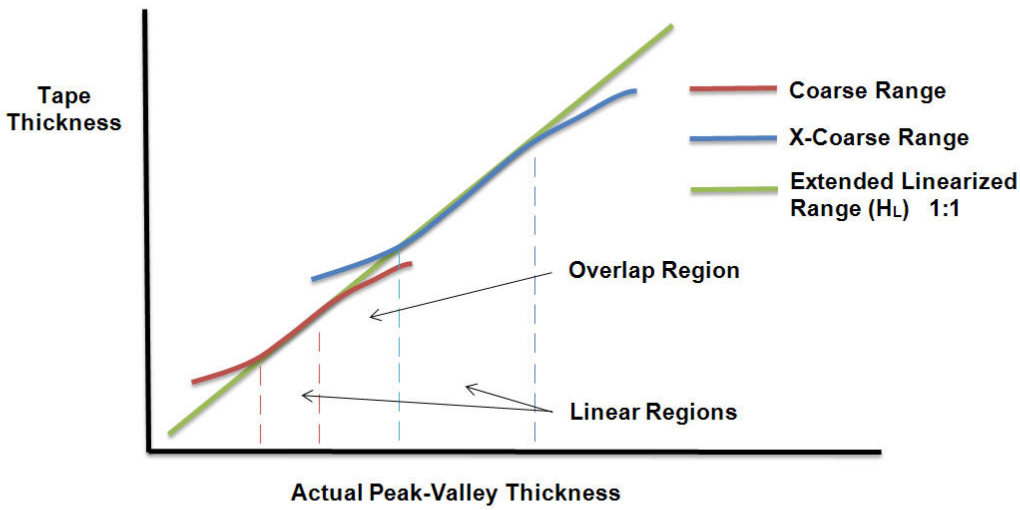

Figure 1

Figure 1 illustrates, schematically, the response function for each grade of tape. The blue curve (**X-Coarse** grade) shows, at the high end of its range, how the tape method reads low where peaks are higher than the foam' thickness, and, at the low end of the range, how tape reads high as it nears full compression. In between, **X-Coarse** exhibits a relatively linear response

The red curve (**Coarse** grade) shows similar behavior, but, because the foam is thinner, at a lower level of profile.

Ideally, the combined response of **X-Coarse** and **Coarse** grades would follow the green line. The procedure that follows illustrates how one maps the actual response curves onto this line.

The exercise proceeds in two steps.

In the first equations, f_C and f_{XC}, the response functions described above, relating replica thickness, $H_o = H_{observed}$, to digital stylus roughness, R_t, are derived for each grade of tape:

$$R_t = f_C(H_o) \qquad \text{and} \qquad R_t = f_{XC}(H_o)$$

Provided the measuring instrument's processor has been set to the appropriate grade, **Coarse** or **X-Coarse**, a processor's application of either f_C or f_{XC} to a replica thickness will have the effect of compensating for that grade's foam response non-linearity. It does so, however, by converting H_o to an R_t -equivalent value, which is only *approximately* equal to a replica profile.

In a second step, this R_t value is mapped to a least squares straight line fit to the combined **Coarse**/**X-Coarse** replica tape response curve and it is the resulting linearized value of replica method profile, H_{lin}, that is reported by the instrument.

Over most of replica tape's 20 to 115 um (0.8 to 4.5 mils) full range of applicability departures from linearity are small compared with the uncertainty of measurement. Places where it makes the most difference are at the upper and lower ends of the range and at the edges of the overlap region. In all cases, the offsets are less than the quoted gage error of 5 um (0.2 mils). This is illustrated in Figure 2.

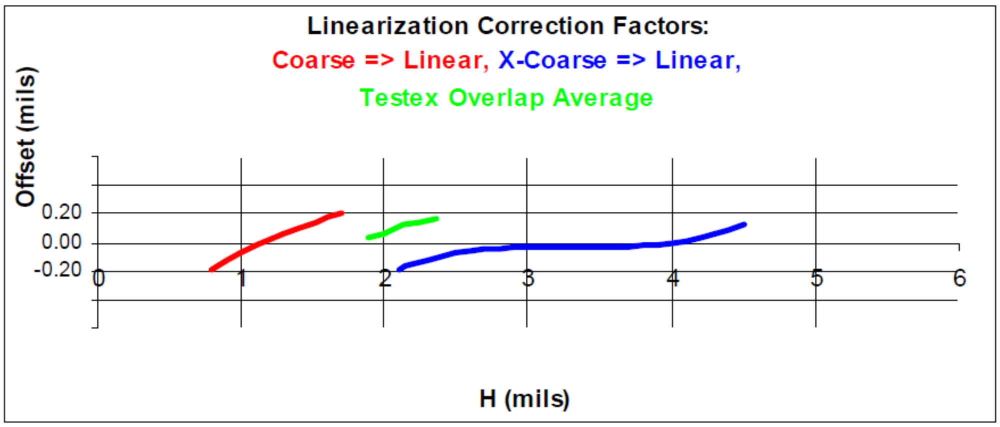

Figure 2

Currently, Testex recommends applying an averaging algorithm when readings obtained with the two grades both fall in the 38 to 64 um (1.5 to 2.5 mil) overlap window. This algorithm yields reasonably accurate profiles (green curve in Figure 2), but is inconvenient. Linearization offers the prospect of accurate profile measurement using a single grade depending on whether the profile is above or below 50 um (2.0 mils), the center of the overlap window. A processor-based gage can be programmed to instruct a user when to switch grades.

Overall, with linearization the process of obtaining a measurement is simplified, its reliability is increased, the averaging procedure is eliminated, the possibility of operator error is reduced and data recording and analysis are made substantially more convenient.