DEVELOPMENT OF A NOMOGRAM FOR SELECTION OF A VISCOELASTIC FREE LAYER DAMPING MATERIAL

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ABSTRACT

During recent years the University of Dayton Research Institute (UDRI) has implemented the concept of design, development, and production of viscoelastic damping materials to attain customer-specified damping performance. The desired damping performance may be for a new application or may be for an improvement that substantially increases the damping over that being obtained from the customer's currently used material. Usually several new candidate materials are produced in trial quantities and their damping properties are evaluated by standard vibrating beam tests. Then analytical estimates are made of their performance in the customer's system configuration. The entire procedure may be repeated several times as improvement trends due to material component ratios and processing variables are exploited. UDRI has developed a System Damping Nomogram (SDN) for free layer damping systems whereby the relative system damping performance of competing materials can be shown over a temperature range of interest by plotting data points extracted from the Reduced Temperature Nomograms (RTN) of the materials. As the new materials are characterized by vibrating beam tests, the system damping performance that results from their use can be determined and compared to previous material results by plotting appropriate data on the SDN. The development and use of the SDN will be explained.

INTRODUCTION

There are many ways to display the performance of a damping system, whether in lists or tables or graphs. We are considering here the performance of a configuration of a particular damping material installed to a structure, not the damping properties of the material itself. Those who work primarily or frequently towards the alleviation of vibration-induced noise or structural fatigue failures by use of the damping methodology usually are comfortable with any of these damping performance representations. Your boss will usually be in this category; however, your customer may or may not be in it. The system damping performance nomogram (SDN) presented here provides a clear picture of how damping material property changes affect the damping performance of a specific damping system. It is useful for convincing yourself, your boss, your customer, and especially people who are peripheral to the problem but have authority to make program decisions, that you are achieving significant system performance improvement. In the programs discussed here, the performance improvement is obtained by formulation modifications of a damping material to improve the performance of a damping system specified by the customer.

I want to make it clear here that most of the material development work we perform for both government and industrial customers is restricted from public distribution at various security classification levels. Therefore, the example used for this paper was not a real project.

DEVELOPMENT OF THE SYSTEM DAMPING NOMOGRAM

Damping system design, as well as the development of the SDN, requires certain knowledge about the vibration problem which is being addressed. This includes:

1. the frequency of the primary vibration resonance of concern;
2. the structural temperature or temperature range at which the vibration occurs;
3. the configuration and material properties of the structural component(s) involved; and
4. the configuration of the desired damping system, or at least the configuration limitation parameters of the damping system.

When these facts are known, the best damping material currently available to solve the problem can be selected. Alternatively, a special damping material can be formulated with damping properties which fit the problem better. The parameters of the problem selected as an example are the following. The structure is a cantilevered aluminum beam and shows a high resonant vibration measured to be the second bending mode at 400 Hz in the operational temperature range of 40 to 70°F. For whatever reasons, a free layer damping system is required with the damping layer no thicker than the aluminum to which it is installed. This is, of course, a simpler problem with a more clear definition than you usually encounter.

We want to generate an SDN, specific to the problem, upon which we can plot the damping properties of elastomeric polymer materials which we might use as the free layer damping material. The SDN should show us the system damping achieved at 400 Hz over the temperature range of 40 to 70°F for each damping material under consideration. The SDN layout data can be generated easily by a damping system prediction computer program. Our program uses the beam damping equations of Ross, Kerwin, and Ungar (R-K-U Equations); and the Oberst Equation. In this case we use the free layer cantilever beam adaption of the Oberst Equation, one of the many options in the program. In addition to the configuration information, required material properties of the structure are entered to the program as are a range of the damping material properties of elastic modulus (Young's modulus) and loss factor, and also the expected density of the damping layer material. Structural dimensions may have to be varied somewhat to achieve the desired resonance mode at the structure's resonance frequency.

The computer printout for this example, showing input data and the calculated system damping loss factors and vibration frequencies, is shown in

Figure 1. The SDN is layed out from the material and system loss factor values in this list, and is shown in Figure 2. The system and material loss factor scales of the SDN usually are adjusted after evaluation of several candidate materials' damping performance.

USING THE SDN

Use of the SDN requires knowledge of the loss factor and elastic modulus, at the specified frequency and over the specified temperature range, of the candidate damping materials. This information is all incorporated in the "Reduced Temperature Nomogram" (RTN) depiction of material properties, developed by Dr. Dave Jones of AFWAL/ML with the cooperation and/or assistance of several others. It is assumed that the reader is familiar with the RTN and its use. Loss factor and modulus equations are commonly fitted to damping material test data displayed on the RTN. The equations then can be used to determine coincident values of damping material properties or they can be determined manually on the RTN. The manual method was used for this example.

Figure 3 shows the RTN of a rather poor example of a free layer damping material, for this or any other problem. The drafting construction to pick material properties values for use on the SDN are shown on this figure. The 400 Hz frequency line is drawn first. Then horizontal lines are drawn through the loss factor curve at convenient values and verticals are drawn through those intersections which extend through the 400 Hz line and the modulus curve. Then horizontals are drawn through the modulus curve intersections with the verticals to make it easy to determine modulus values. Pertinent data is the 400 Hz value, the circled loss factor and modulus data point values, and the temperature values at the intersections of the verticals with the 400 Hz line. The loss factor-modulus data points then are plotted on the SDN with the appropriate temperature noted at each data point, as shown in Figure 4. This SDN shows rather poor damping performance, though you might think otherwise if you had a part that was failing at 10 or 20 percent of its design service life. The damping performance does cover the desired temperature range, but we can do better.

COMPARISON OF TWO SIMILAR DAMPING MATERIALS

Figures 5 and 6 show the RTN's of two very similar materials which appear to be different because the nomograms are plotted with different T_0 values but identical reduced frequency scales. Figures 7 and 8 show the drafting construction to pick the data values for the SDN. That SDN is shown in Figure 9 and does indicate that the two materials are fairly close in free layer damping performance, but material A is better.

One problem with the SDN is the difficulty in following the temperature trend of the damping performance comparison at the glassy end of the transition region where elastic modulus values are high and loss factor values are low. The solution to this problem is to plot the system loss factors versus temperature over the desired temperature range. That comparison plot for these two materials is shown in Figure 10 for the temperature range of 30 to 80°F, just in case this range turns out to be different than we were told when we started. Figure 10 shows more clearly that material A provides better damping. Remember that this is not a real problem. We can obtain three to four times this level of damping with an optimum free layer damping material formulated to fit specific problem conditions.

We have found the SDN to be useful. It is not difficult to generate or to use. It and the system damping versus temperature plot have been used to convince people that significant progress was being made. Damping performance improvements in systems using materials developed under this monitoring method have been almost exactly what the SDN predicted. The analysis is capable of predicting damping system performance on numerous beam and plate configurations for both free layer and constrained layer damping systems. Real problem solutions usually achieve considerably higher system damping levels than was shown by this example.

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BEAM PARAMETERS:
  BEAM TYPE:                                  CANTILEVER
  FIRST BEAM BENDING MODE NUMBER:               2
  LAST BEAM BENDING MODE NUMBER:                2
  BEAM LENGTH:                                11.000     in
  BEAM THICKNESS:                               .250     in
  BEAM DENSITY:                                 .1000    lb/cu in
  BEAM YOUNG'S MODULUS:                        1.000E+07 psi
  DAMPING MATERIAL DENSITY:                     .0600    lb/cu in
  DAMPING MATERIAL LOSS FACTOR:
  DAMPING MATERIAL THICKNESS:                   .250     in
BEAM COATED ON ONE SIDE

MODE NUMBER 2
BARE BEAM FREQUENCY IS      410.96 HZ

     MATERIAL LOSS FACTOR IS .5                    MATERIAL LOSS FACTOR IS 1
                  SYSTEM                                        SYSTEM
 MATERIAL          LOSS       SYSTEM            MATERIAL         LOSS      SYSTEM
 MODULUS          FACTOR     FREQUENCY          MODULUS         FACTOR    FREQUENCY
---------------------------------------      ---------------------------------------

 2.000E+06        .29167      581.2             2.000E+06       .58333      581.2
 1.000E+06        .24915      480.9             1.000E+06       .49830      480.9
 7.500E+05        .22325      449.3             7.500E+05       .44650      449.3
 5.000E+05        .18324      413.7             5.000E+05       .36648      413.7
 4.000E+05        .16110      398.1             4.000E+05       .32219      398.1
 3.000E+05        .13386      381.6             3.000E+05       .26773      381.6
 2.000E+05        .09985      364.0             2.000E+05       .19970      364.0
 1.500E+05        .07956      354.8             1.500E+05       .15911      354.8
 1.000E+05        .05654      345.2             1.000E+05       .11307      345.2
 7.500E+04        .04384      340.3             7.500E+04       .08768      340.3
 5.000E+04        .03025      335.2             5.000E+04       .06049      335.2
 3.000E+04        .01867      331.2             3.000E+04       .03733      331.2
 1.000E+04        .00640      327.0             1.000E+04       .01281      327.0

     MATERIAL LOSS FACTOR IS 1.5                   MATERIAL LOSS FACTOR IS 2
                  SYSTEM                                        SYSTEM
 MATERIAL          LOSS       SYSTEM            MATERIAL         LOSS      SYSTEM
 MODULUS          FACTOR     FREQUENCY          MODULUS         FACTOR    FREQUENCY
---------------------------------------      ---------------------------------------

 2.000E+06        .87500      581.2             2.000E+06      1.16667      581.2
 1.000E+06        .74745      480.9             1.000E+06       .99661      480.9
 7.500E+05        .66975      449.3             7.500E+05       .89300      449.3
 5.000E+05        .54972      413.7             5.000E+05       .73296      413.7
 4.000E+05        .48329      398.1             4.000E+05       .64439      398.1
 3.000E+05        .40159      381.6             3.000E+05       .53546      381.6
 2.000E+05        .29955      364.0             2.000E+05       .39940      364.0
 1.500E+05        .23867      354.8             1.500E+05       .31823      354.8
 1.000E+05        .16961      345.2             1.000E+05       .22614      345.2
 7.500E+04        .13151      340.3             7.500E+04       .17535      340.3
 5.000E+04        .09074      335.2             5.000E+04       .12098      335.2
 3.000E+04        .05600      331.2             3.000E+04       .07467      331.2
 1.000E+04        .01921      327.0             1.000E+04       .02562      327.0
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Figure 1. COMPUTER RUN TO GENERATE NOMOGRAM LAYOUT DATA.

SDN For Free Layer on Aluminum Cantilever Beam
Damping Layer Thickness = Aluminum Beam Thickness

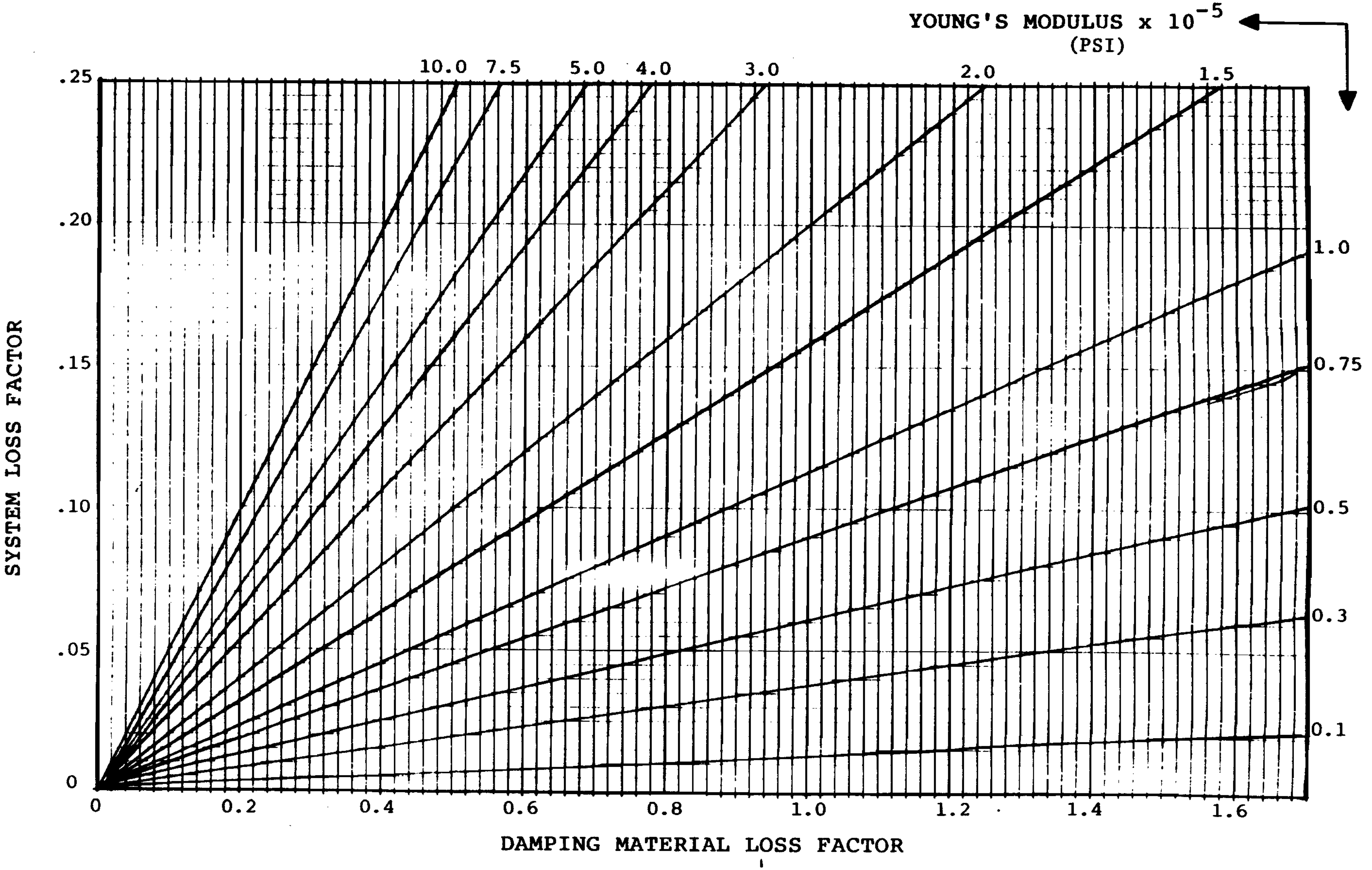

Figure 2. SYSTEM DAMPING NOMOGRAM.

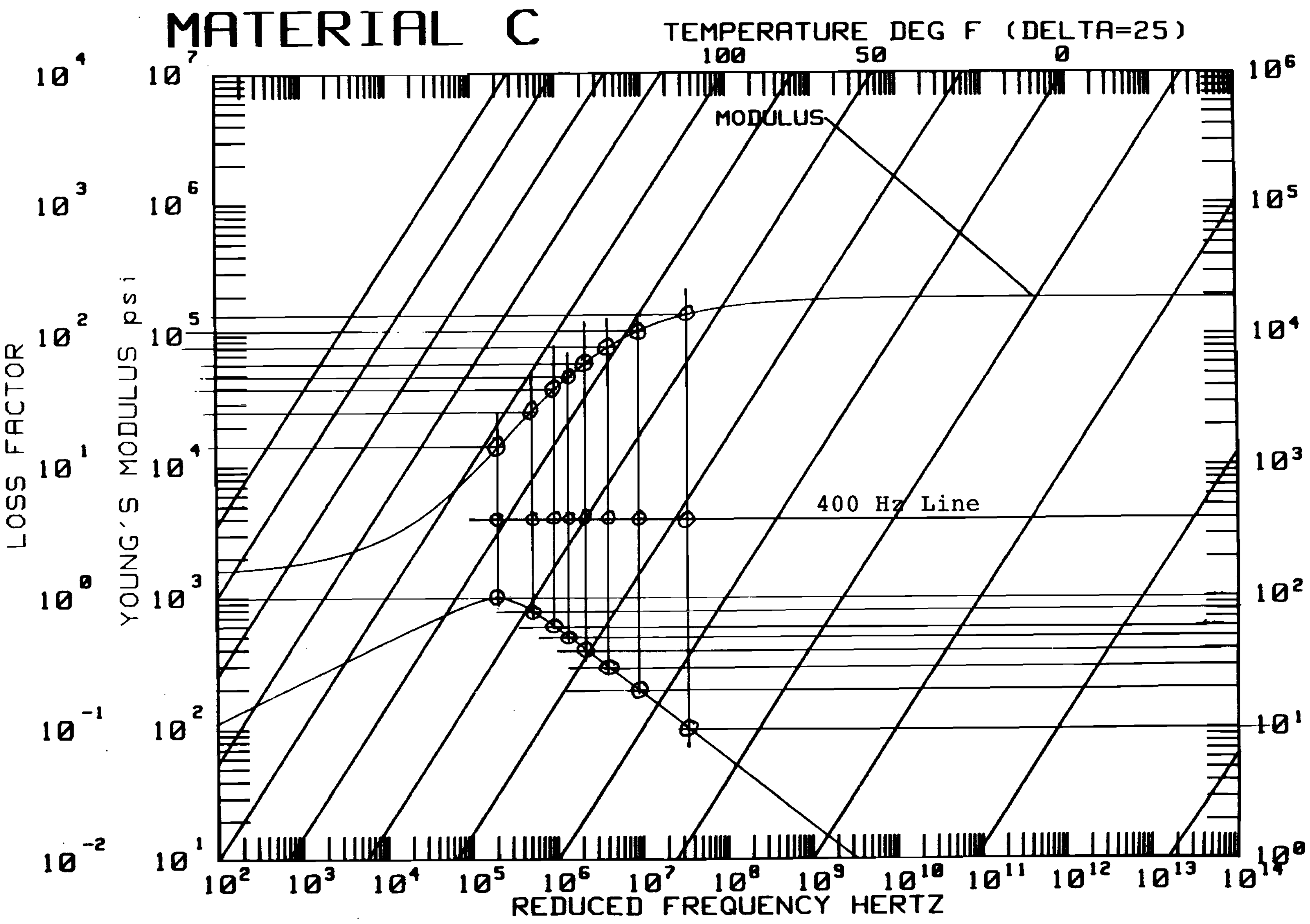

Figure 3. MATERIAL C REDUCED TEMPERATURE NOMOGRAM WITH DATA POINT LAYOUT.

SDN For Free Layer on Aluminum Cantilever Beam
Damping Layer Thickness = Aluminum Beam Thickness

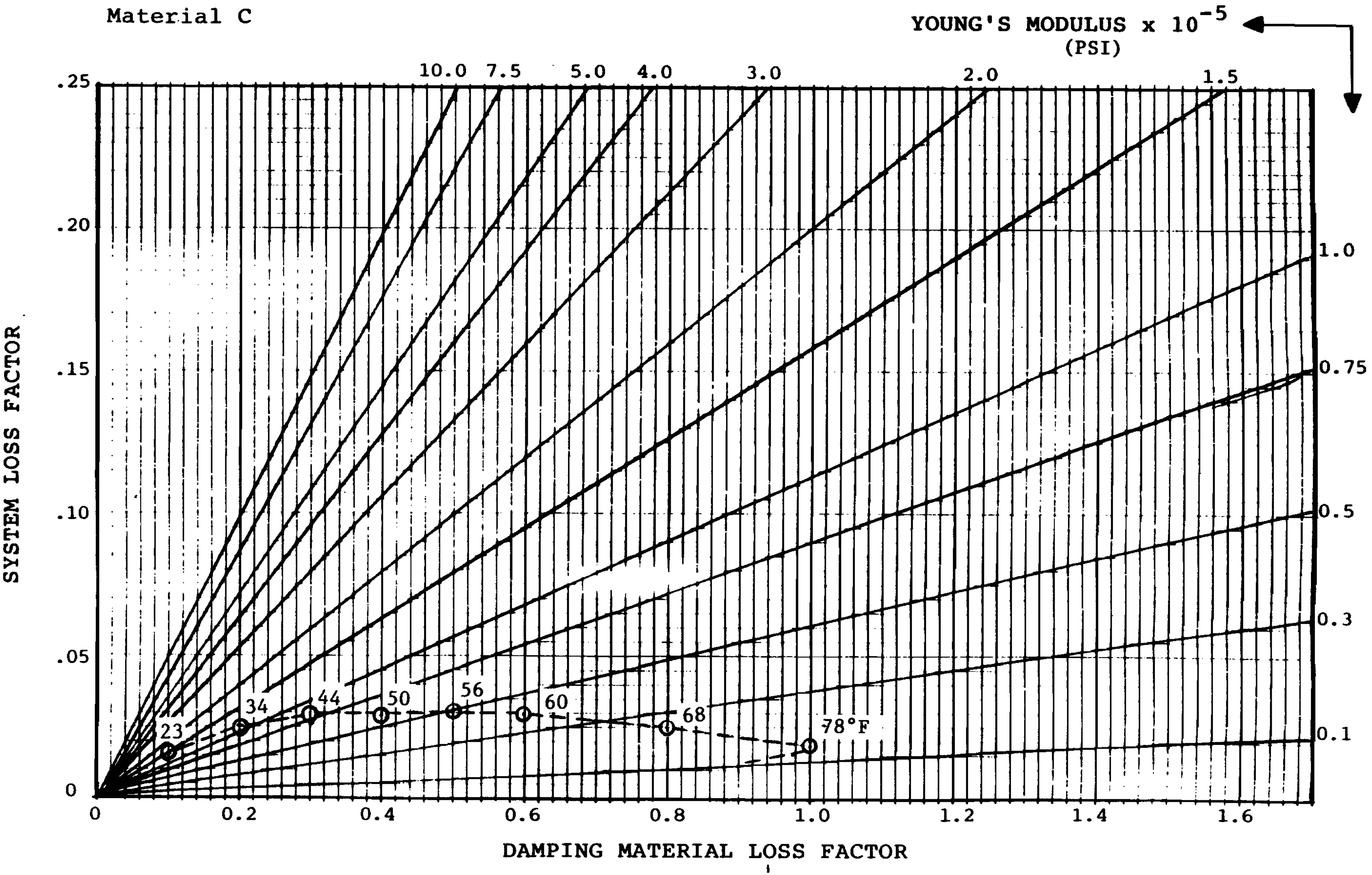

Figure 4. MATERIAL C SYSTEM DAMPING NOMOGRAM FOR EXAMPLE CONDITIONS.

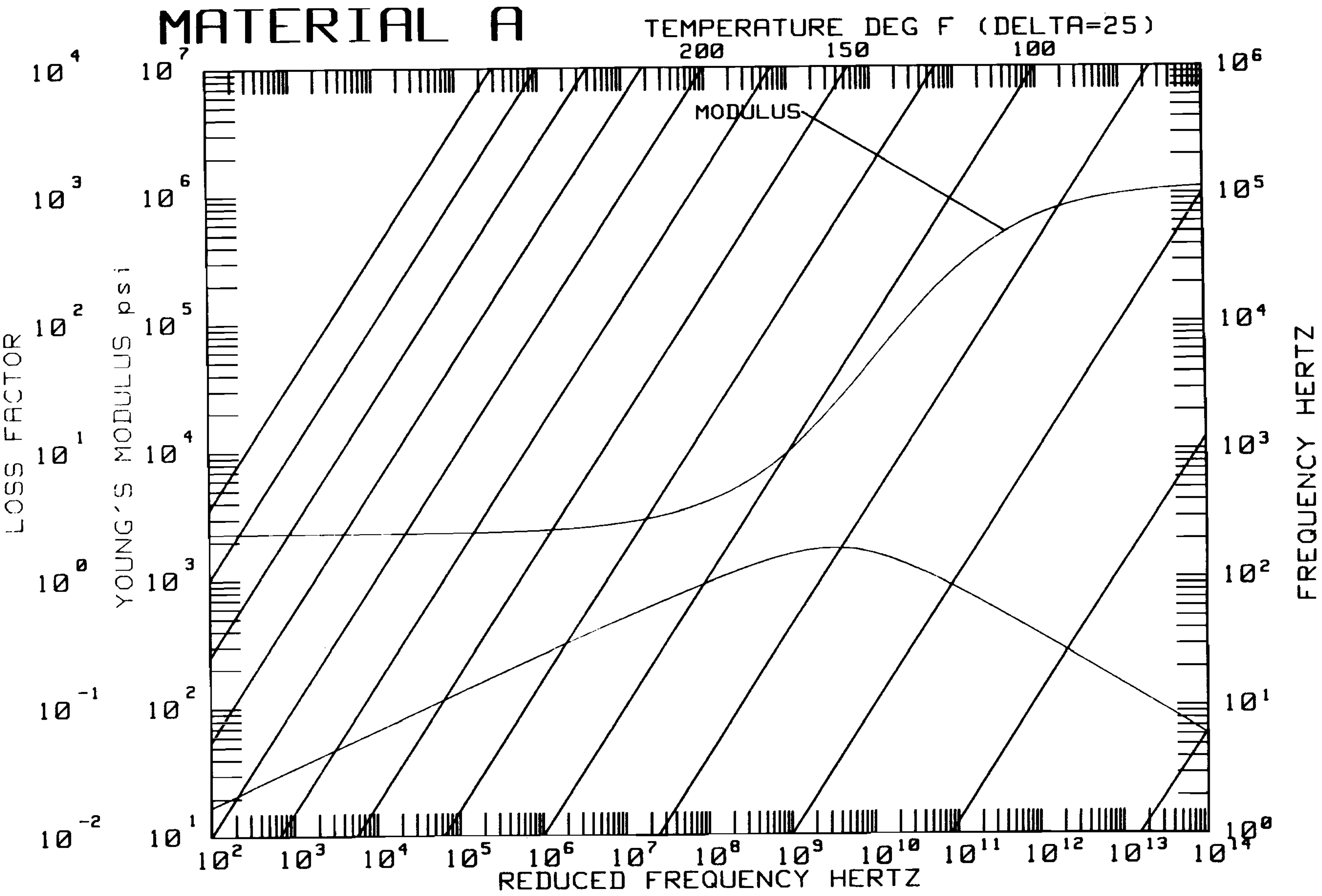

Figure 5. MATERIAL A REDUCED TEMPERATURE NOMOGRAM.

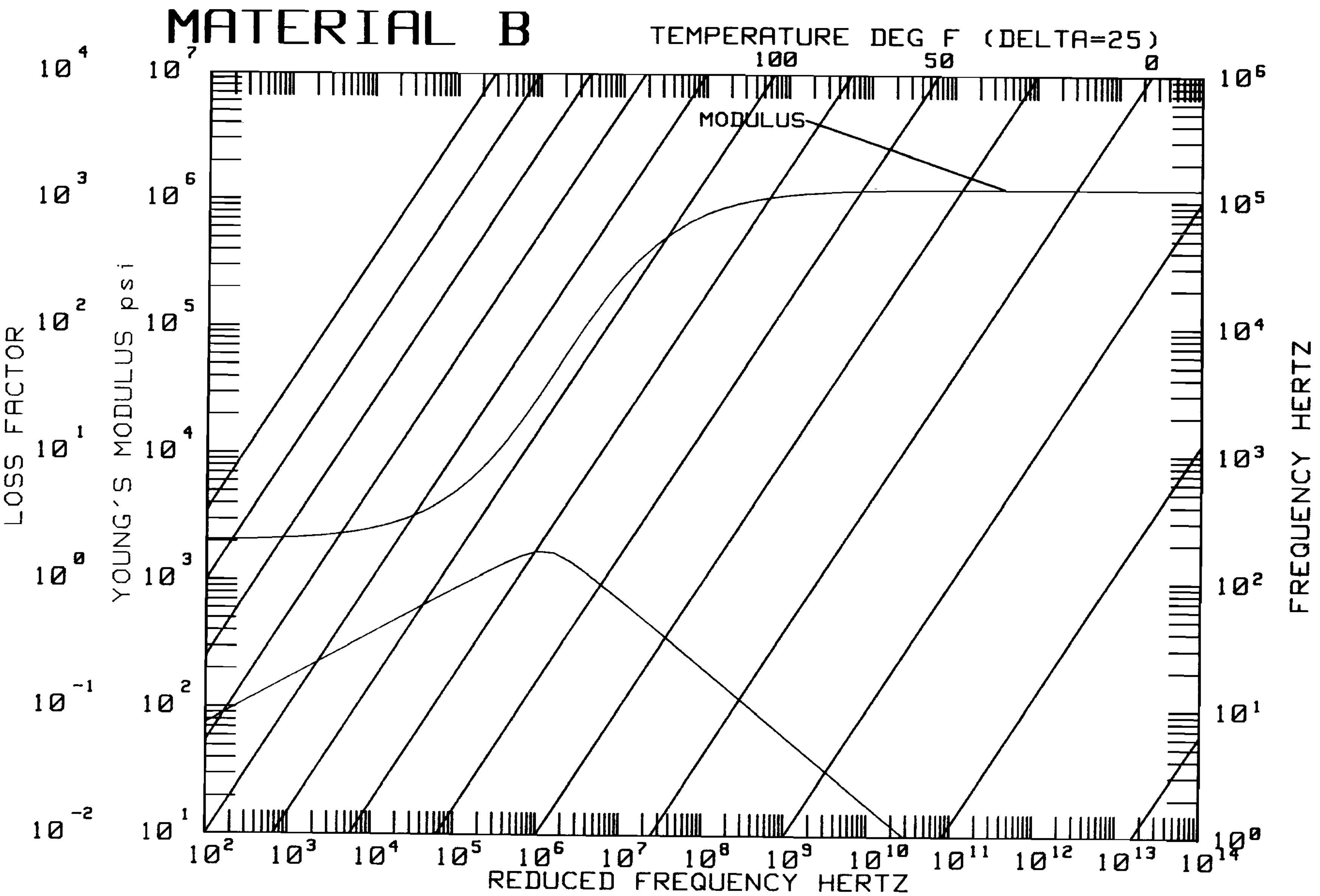

Figure 6. MATERIAL B REDUCED TEMPERATURE NOMOGRAM.

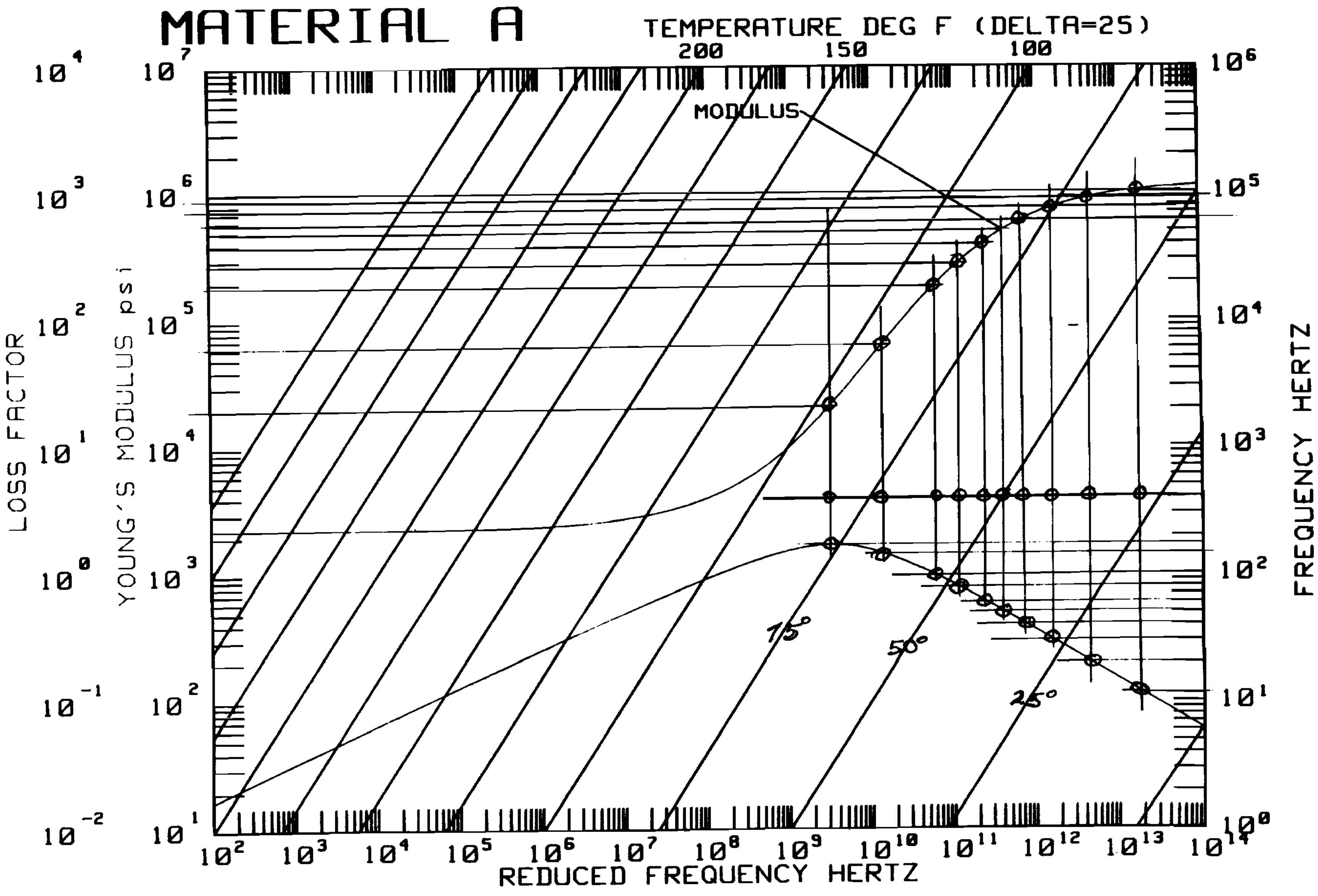

Figure 7. MATERIAL A REDUCED TEMPERATURE NOMOGRAM WITH DATA POINT LAYOUT.

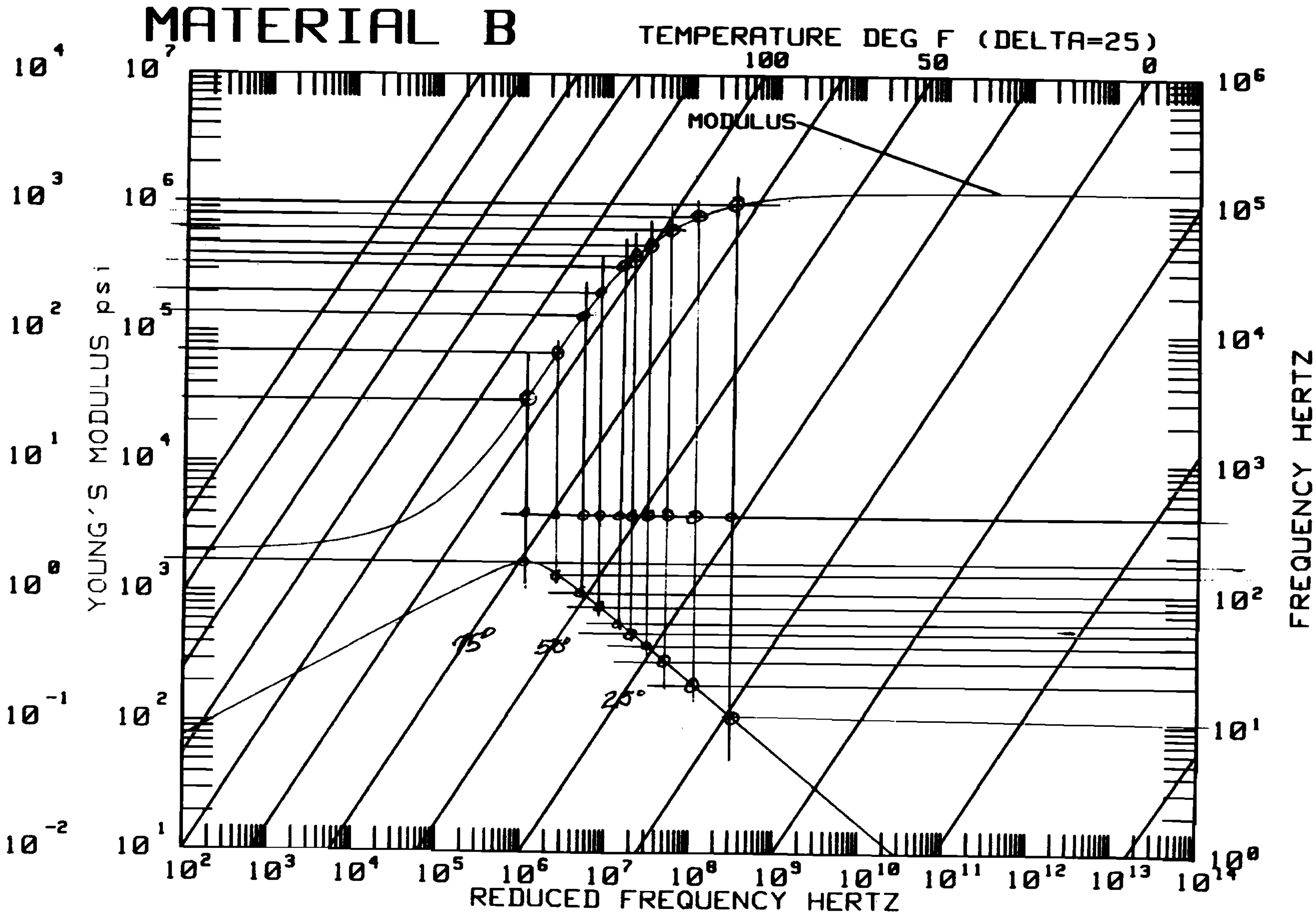

Figure 8. MATERIAL B REDUCED TEMPERATURE NOMOGRAM WITH DATA POINT LAYOUT.

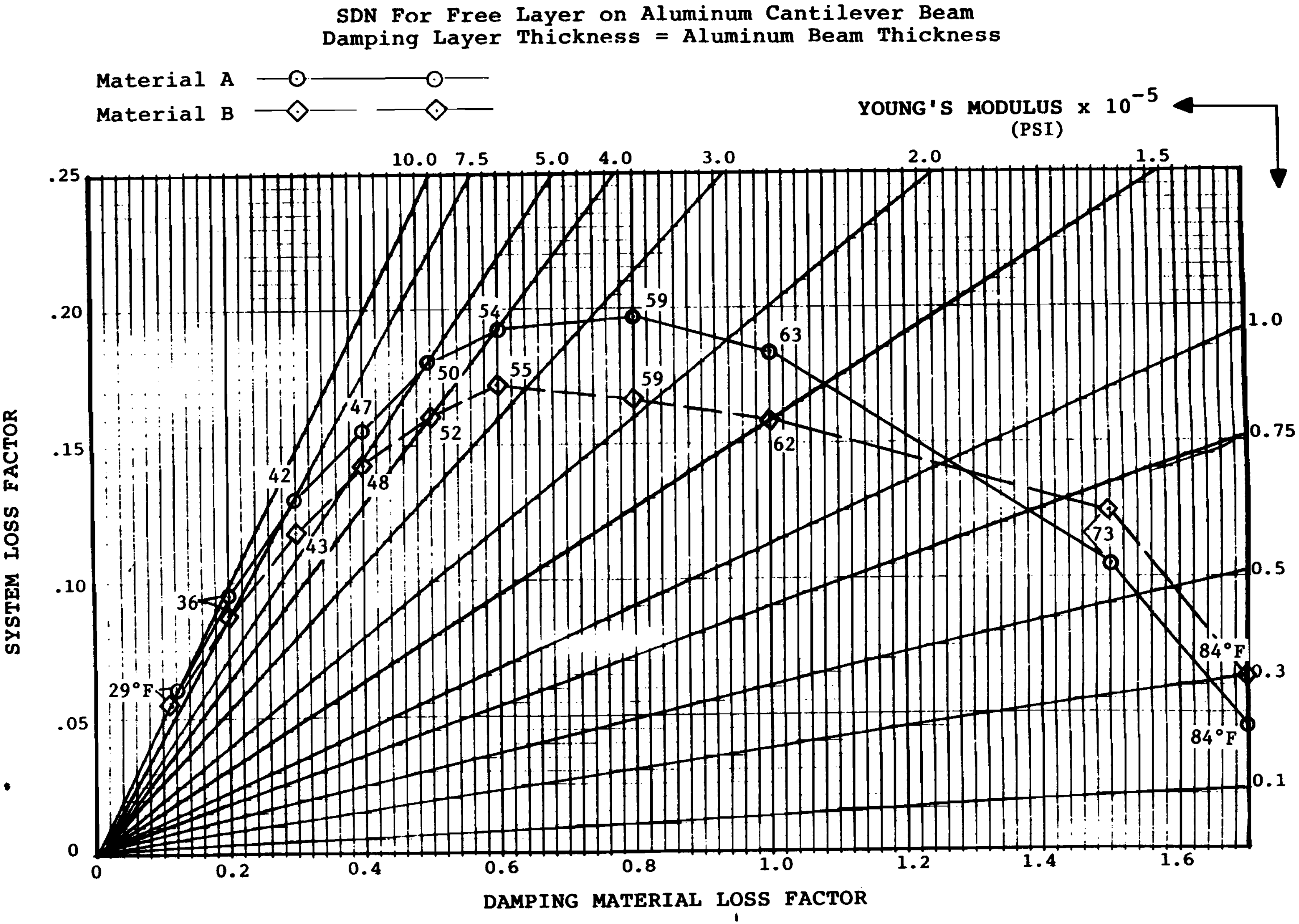

Figure 9. SYSTEM DAMPING COMPARISON FOR MATERIALS A & B FOR EXAMPLE CONDITIONS.

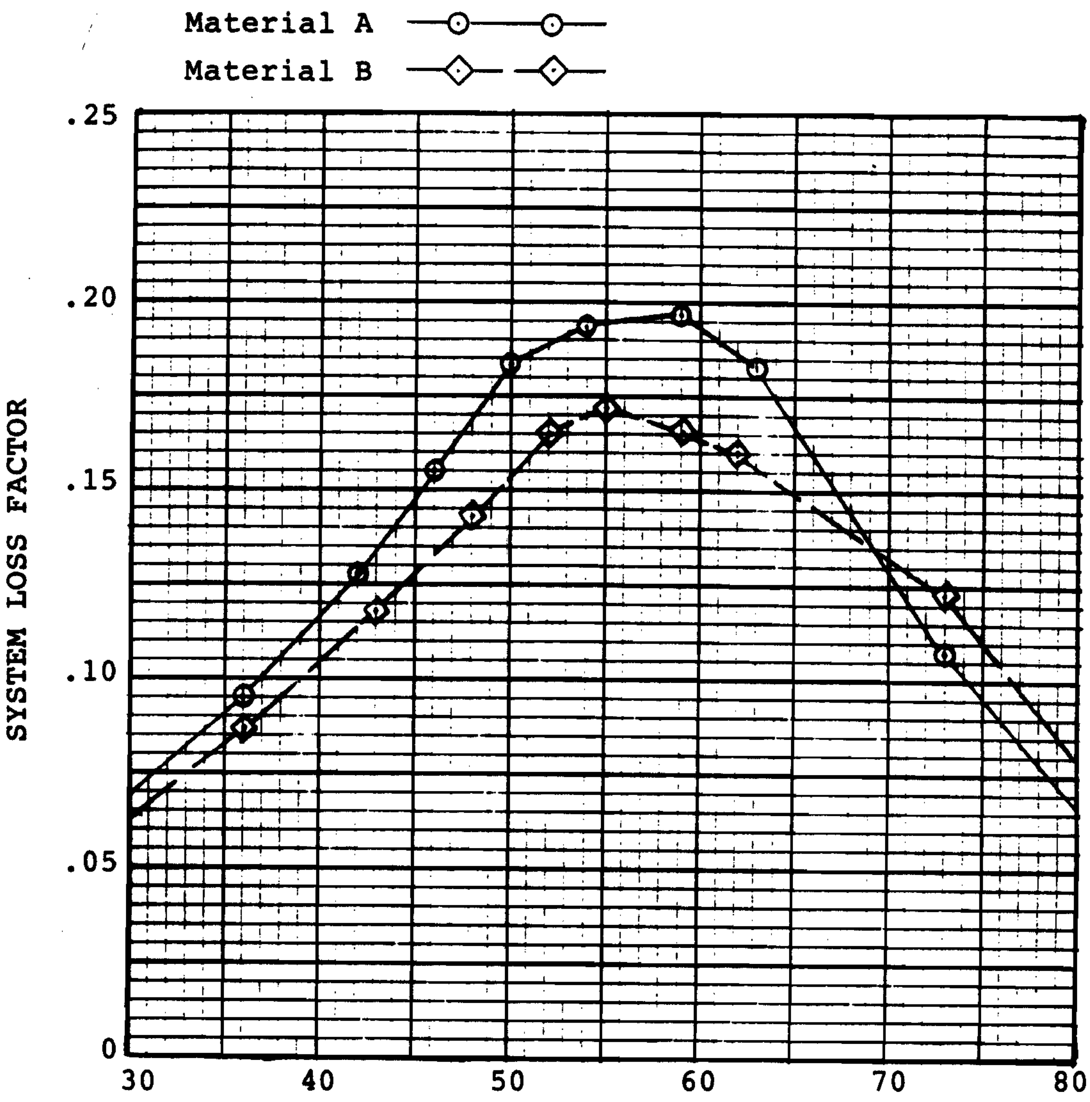

Figure 10. SYSTEM DAMPING VERSUS TEMPERATURE FOR MATERIALS A & B FOR EXAMPLE CONDITIONS.