Conclusions

The response to static load components of a machine tool dynamometer may be analyzed in detail using no undue complex or expensive equipment. There is no substitute for the kind of information obtained in this way, if excessive errors due to cross-sensitivity are to be avoided. Such errors may occur even when the unit is used well within its useful load range, yet the user may be caught unaware if he does not adopt proper precautions.

Even when there are less than six output channels (which is the rule in machine-tool work), the error level may still be controlled to some extent. A knowledge of the operating characteristics of the unit and, at least, a good guess of an upper bound value of all load components are required.

Small variations in output signal may be caused by real changes of magnitude of cutting forces, and/or shifts of resultant cutting force. To ignore the real cause does not matter very much, for such applications as machinability studies or tool design, where minimal variations in cutting forces are immaterial [17]. On the other hand, particular investigations in metal cutting mechanics [18] rely heavily on accurate estimation of cutting force components. A critical appraisal of dynamometer performance is then needed if meaningful results are to be derived.

Static force components only were dealt with so far. When dynamic components are to be taken into account, the problem becomes more involved, as most of the coefficients turn out to be frequency dependent quantities [19]. Experimental methods were devised for solving this kind of problem [20]. It must be realized that in order to apply these methods elaborate, special purpose instrumentation and adequate on-line computing facilities are needed.

References


**DISCUSSION**

J. Gaindhar and A. O. Schmidt

This paper is a significant contribution towards a more adequate calibration of dynamometer performance under static loads. Normally, moments are not considered as major components in single point tool-holder type dynamometers, e.g., for lathes, but they are present due to misalignment of the loading point. For such cases, the author has successfully analyzed the cross-sensitivity effects of various channels while calibrating a multicomponent dynamometer by an easy technique, which requires only simple fixtures and no special equipment. However, while explaining the procedure, the author has not stated the effect of difference of response when the load is gradually increased or is gradually reduced. This might cause some hysteresis effects in the dynamometer.

The influence of cross-sensitivity could be checked by loading the dynamometer to its full rating instead of only one-fourth. In the preliminary test for any experimental design, the two extreme levels of a variable—maximum and minimum—should be taken. The number of replications has been mentioned neither in the preliminary testing nor during the factorial experimental design. The question arises: Why are second order interaction terms considered additional independent variables? Are they not dependent variables?

Since dynamometers are used under dynamic loading conditions, how is the cross-sensitivity response, measured by the static loading method, correlated with the dynamic loading effects in actual practice?

It would be helpful to those of us who use metal cutting dynamometers if Professor Levi would discuss the comparative improvement of the reported calibration procedure relative to that with only one fixed reference point.

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Author's Closure

The questions raised by Mr. J. Gaindhar and Dr. A. O. Schmidt concern several important points.

Hysteresis effects may readily be taken into account with the technique proposed. All that is needed is the introduction of an additional dummy variable, e.g., of unit value and positive sign for increasing loads, negative for decreasing. Details were given concerning the application of the procedure proposed only in those directions in which some improvements over traditional techniques were expected. Currently used methods [21, 22] are believed to be quite adequate for evaluating hysteresis effects. Such effects do not exceed 0.2 percent of the full rated signal for the unit tested.

It is agreed that the full load range should be covered during tests. Proper hoisting equipment and an adequate set of deadweights were however not available at the time of the tests. It was assumed that the results obtained even within a narrow load range might be of some interest to other workers in the same field, and could thus warrant publication. Later on, the installation of an electric hoist and the addition of deadweights made full-scale testing feasible.

The factorial experiment was replicated twice. It is true that the values of independent variables introduced to take care of second order effects are uniquely determined by the values of first order independent variables. Second order terms were introduced as additional independent variables as a convenient computational arrangement.

As far as their influence on the output signal is concerned, second order and interaction terms may be considered as independent variables, and their effects handled accordingly. All main effects and interactions estimates are in fact orthogonal for factorial designs. Estimates of second order effects not entangled with first order ones provide valuable information to the designer on the amount of load-induced distortions and their implications.

Tests on dynamic cross-sensitivity of machine-tool dynamometers are rather complex to perform. According to published results [19] the ratio between dynamic and static cross-sensitivity effects may be expected to reach the order of magnitude of the dynamic magnification factor under resonance conditions. As damping is seldom very large this means that dynamic errors may well exceed static ones by one or two orders of magnitude. Remedial action may be taken by full dynamic compensation with accelerometers. This is however a very expensive technique both on the unit and the instrument system.

Table 2 and Fig. 7 offer some quantitative answers to the last question. When force components are measured through moments, see, e.g., [12, 23–25] then an uncorrected shift of loading point of 1 millimeter may entail errors in the 1 to 5 percent range for components of comparable magnitude.

If the component under consideration is much smaller than the others, as is often the case for radial components both in turning and drilling, errors of 50 percent and more may be caused by cross-sensitivity. The procedure proposed does not always enable the user to make allowances for such effects. It is however believed adequate for pointing out the danger of occurrence of these errors, and at worst for estimating realistically the uncertainties of test results.

Additional References