TOOL HEAT FLUXES DURING CUTTING OF A360 USING BECK'S METHOD

Sean C. McCarty
The University of Alabama
Tuscaloosa, AL, USA

Keith A. Woodbury
The University of Alabama
Tuscaloosa, AL, USA

Y. Kevin Chou
The University of Alabama
Tuscaloosa, AL, USA

ABSTRACT

The energy released during mechanical cutting is carried away by the metal chips and conduction into the tool. This report focuses on determination of the heat fluxes into the tool during cutting using Beck's method.

A small thermocouple is used to measure the temperature rise on the surface of a cutting tool during turning of aluminum A360 cylinders. A detailed model of the tool in FLUENT is used to compute the sensitivity coefficients for the temperature response at the sensor location due to a unit heat flux disturbance at the cutting zone. These sensitivity coefficients are used in Beck's method along with the measured temperature history, to determine the heat flux history at the cutting zone.

EXPERIMENT

The experimental data of Liu (2005) is used in this investigation. Liu's experiment consisted of turning A390 pistons on an engine lathe using tungsten carbide cutting inserts.

A picture of the lathe, tool holder, and tool can be seen in Figure 1.The outer diameter of the piston (not in the chuck in the figure) was cut down by 20mm. The speed of cut was set at 5.0 m/s while the feed was set to 115 mm/rev. The depth of cut was 2mm.

Cutting temperatures were measured during the experiment by an attached type-K thermocouple 2 mm behind and 1 mm down from the cutting zone as indicated in Figure 2. Temperatures were recorded every 0.1 second using a National Instruments digital data acquisition system.

FORWARD MODEL

The forward model used in this investigation to compute the temperatures for a given heat flux history is a finite volume numerical model implemented in the commercial solver

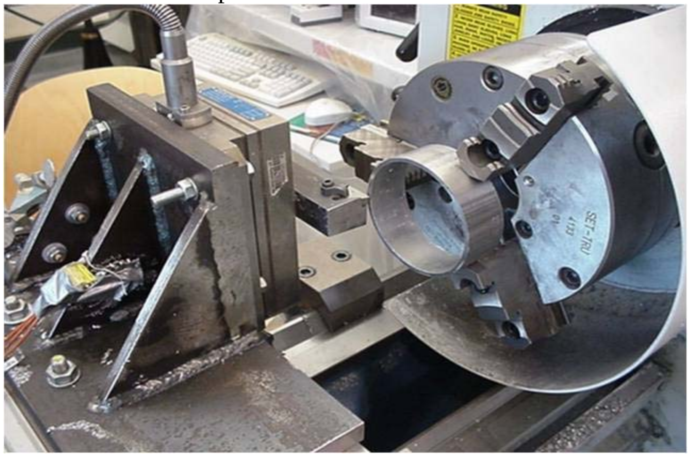

Figure 1 Liu's Experimental Setup (Liu, 2005).

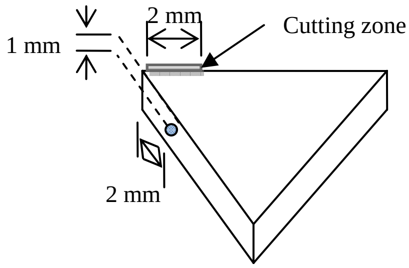

Figure 2 Location of Thermocouple Sensor.

FLUENT®. This model is the same as that used by Duvvurri (2006). The mesh used in the model is illustrated in Figure 3. Only a relatively small portion of the entire tool holder was modeled, because computational experiments with a larger model showed that much of the tool holder arm remained adiabatic throughout the cutting process. Temperature-dependent thermal properties were used.

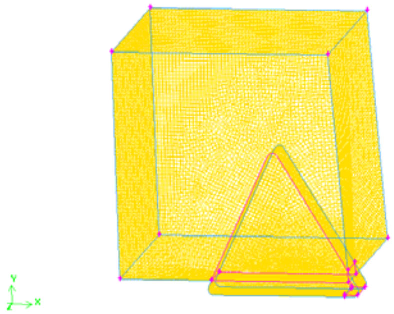

Figure 3 Finite element model of tool and tool holder.

BECK'S METHOD

The heat flux for the given temperature data were estimated using Beck's sequential function specification method (SFSM) (Beck, et al., 1985). This method is based on Duhamel's integral which is used to solve transient heat conduction problems.

Duhamel's summation is a numerical approximation to the integral which is the result of the superposition principle. Although the direct problem under consideration is three-dimensional, the heat flow is dependent only on a time varying heat flux acting uniformly over a prescribed portion of the boundary. Therefore, Beck's method can be applied in its simplest form for one sensor and one unknown heat flux.

To apply Beck's SFSM a specific functional variation of heat flux over each time step must be assumed. For simplicity, q(t) is assumed to be a piecewise constant function of time. The equation for the function specification method, assuming the heat flux as constant over each time step, is

$$q = \frac{\sum_{i=1}^{r}\left(Y_{M+i-1} - \hat{T}_{M+i-1}\Big|_{q_M=......0} \right)\varphi_i}{\sum_{i=1}^{r}\varphi_i^{\,2}} \qquad (1)$$

where Y is the given temperature, M is the total number of time steps, φ is the sensitivity coefficient. $\hat{T}$ is the calculated temperature due to the estimated heat flux and it can be determined from Duhamel's summation:

$$\hat{T} = \sum_{i=1}^{M-1} \hat{q}_i \Delta\varphi_{M-i+r-1} + T_0 \qquad (2)$$

where $\hat{q}$ represents the estimated heat flux at time t_M, and r is the number of future temperatures.

The sensitivity coefficients were computed using the forward solver using the definition: "Sensitivity coefficients are the temperature rise at a point in a domain in response to a unit step change in disturbance at the boundary." However, in the present case, in consideration of the magnitude of heat fluxes expected, a "unit step" of 10 MW/m^2 was used.

The method was implemented into an Excel spreadsheet using a Visual Basic macro. The macro implemented Eqs 1 and 2 and retrieved sensitivity coefficients and temperature data from the spreadsheet for calculation. After computing the temperature history, the results are returned as a vector to the spreadsheet as an "Array Function" does in Excel.

RESULTS

The results obtained are seen in Figure 4 along with those obtained by previous investigators (Liu (2005) and Duvvuri (2006)). The results presented for Duvvuri are actually the average of four separate estimations using a Genetic Algorithm-based method. The results from Liu are based on classic heat partitioning methodology used by tribologists and computed from the forces measured during cutting and an average temperature for the cutting process.

The results from the present investigation strongly reinforce those of Duvvuri. Duvvuri's GA-based method required specification of fixed time points for estimation of knots for linear interpolation of the heat flux and precluded estimation of heat flux beyond the end of the cutting time (after about 10.2 seconds).

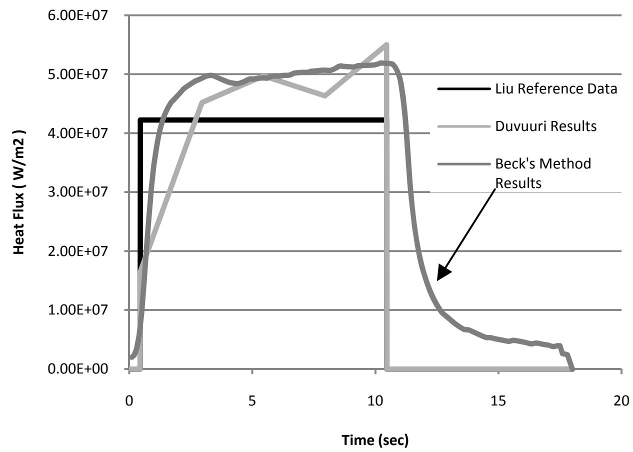

Figure 4 Results compared with those of previous investigators.

Both the present results and those of Duvvuri support the estimate of the constant heat flux to the tool made by Liu (2005). However, the values estimated by the later investigations are about 20% higher than Liu's. Also, the heat flux is seen to vary with time, generally increasing during the cutting process.

CONCLUSIONS

A finite volume forward solver in FLUENT® was used to generate sensitivity coefficients for a three-dimensional heat flow in a cutting tool during machining. These sensitivity coefficients were used in Beck's method to solve the inverse heat conduction problem for the transient heat flux during cutting. The data for the analysis was taken from the experimental work of Liu (2005). Beck's method was implemented into an Excel spreadsheet using VB macros. The results compare favorably with those of previous investigators.

8. REFERENCES

Beck. James V., Blackwell. Ben, St. Clair Jr. Charles R. (1985) *Inverse Heat Conduction: Ill-posed Problems*, (1st Ed.). New York: John Wiley & Sons Inc.

Duvvuri, S. (2006). S*olution of a three dimensional inverse heat conduction problem using genetic algorithms and fluent*. Thesis, obtained from the University of Alabama.

Liu, Jae, (2005). *An investigation on cutting tool temperatures in machining of high strength Al alloys and composites assisted with vortex-tube and heat-pipe cooling.* Dissertation, obtained from the University of Alabama.