# COMPARISON OF TOOL PATH INTERPOLATION ON THE APPLICATION OF THE HSC TECHNOLOGY

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***Abstract.*** *The application of high speed machining of molds and dies with their high complex geometry have made the traditional methods of tool path interpolation normally used by CAM systems, i.e., linear and circular interpolations, the bottleneck of the whole process. These traditional interpolation methods increase the machining time, have a negative influence in the final quality of the surfaces and are a technological limitation for the full application of HSC. As a result, the study of new methodologies on tool path interpolation is becoming one of the main areas of research in manufacturing of molds by HSC Among the different methodologies of tool path interpolation there are the linear, circular and polynomial. The milling experiments were made using work pieces of AISI SAE P20 Steel and the geometry from the NC Gesellschaft test part.*

***Keywords****: Milling, Spline, Tool path Interpolation*

## 1. Introduction

Within the CAD/CAM/CNC chain applied to the development of molds and dies, the tool path is determined based on a tolerance defined by the user of the CAM system, which is applied to the geometric model of the product to be manufactured. In Figure 1 one can observe that this tolerance is directly related to the accuracy of the tool path, to the size of the NC program and, consequently, to the calculation time.

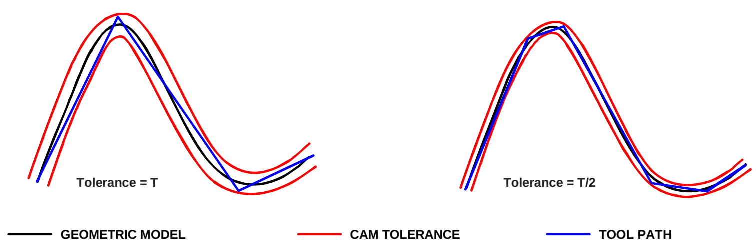


Figure 1. Tool path in function of CAM tolerance

The commercially available CAM systems offer diverse interpolation methods in order to obtain a tool path in the manufacturing of complex surfaces that better adapts to the tolerance range stipulated by CAM.

In traditional manufacturing, in which the demands on the feedrate are significantly less, the tool path interpolation methods were disregarded as a resource for the CAM systems. This turned linear interpolation into the standard due to its mathematical simplicity and ease of use for the programmer.

However, with the application of HSM Technology where the demands on the feedrate are higher, the linear interpolation method begins to create various limitations, primarily in relation to the rate of machining and the accuracy of the geometric model. This has resulted in the reconsideration of the utilization of tool path interpolation in the generation of the NC program (Lartigue *et al*., 2004; Altintas and Erkorkmaz, 2003; Koninckx, and Van Brussel, 2002; Yau and Kuo, 2001; Langeron *et al, 2004*).

Figure 2 illustrates the values of the real feedrate in function of the increase in programmed feedrate obtained in an experiment at the Laboratory for Computer Application in Design and Manufacturing (SCPM/UNIMEP). In these tests the NC program was generated using linear interpolation.

Observe that for a programmed feedrate of up to 1.000 mm/min for the tool machine and tested numerical command, the real feedrate remains constant along the entire geometric model and with the same programmed value. However, as the programmed feedrate increases, the variations of the real feedrate become more pronounced in the more complex areas of the geometric model.

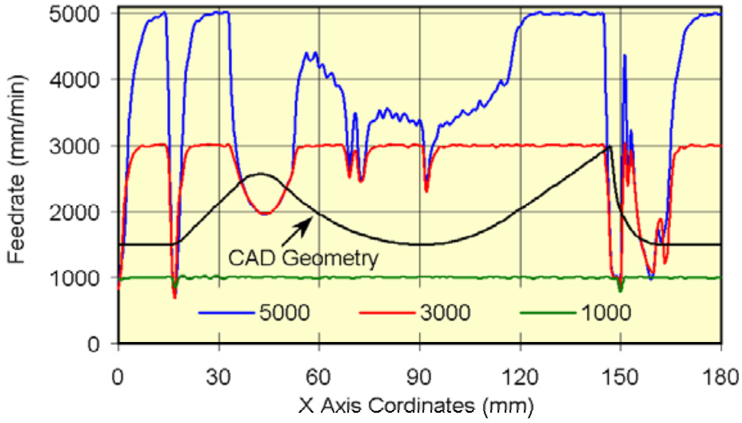


Figure 2. Programmed and real feedrates using linear interpolation

Due to this, the study of new tool path interpolation technologies has become fundamental. Among the existing methodologies, this article will evaluate the linear, circular and polynomial.

### 1.1. Linear Interpolation

In linear interpolation, the CAM system determines the tool path through the interpolation of straight line segments that best adapt to the tolerance range of the CAM system (see Figure 1). These straight line segments are represented by the G01 command of the ISO 6983 programming language. Because linear interpolation uses straight line segments to represent the tool path, it has a simpler mathematical representation than other methods. For this reason it has become the most popular method for representing tool paths.

However, as can be observed in Figure 2, the increased feedrate from the new HSC technology have resulted in making the use of linear interpolation for representing the tool paths technologically limiting.

This fact occurs primarily because of one technical characteristic of the numerical command called block processing time (BPT). This is the time that the CNC takes to read a block of information, process and transmit this information for the machine to execute the movement (Arnone, 1998).

Therefore, despite the difficulty in determining the processing time of the machine tool, its study is of extreme importance, for if the block processing time is longer than the block execution time, the machine will reach the end point of the segment before the information for the next movement is available.

In this case the more modern CNCs automatically reduce the programmed feedrate to be compatible with the processing time, resulting in a lower real feedrate and, consequently, a longer machining time.

### 1.2. Circular Interpolation

Through this method, the CAM system determines the tool path through an association of straight line segments and arcs that best adapt to the tolerance limits of the CAM system. These segments are represented by the G01, G02 and G3 commands of the ISO 6983 language (see Figure 3).

While with linear interpolation the complex surfaces are represented only by straight line segments, in the circular interpolation these small segments, when possible, are substituted by arcs, resulting in a smoother tool path, smaller NC programs and, consequently, better real feedrate performance.

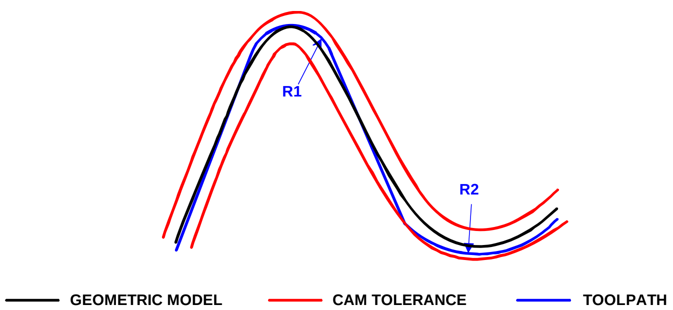


Figure 3. Circular interpolation representation

### 1.3. Polynomial Interpolation

The application of polynomial interpolation was the beginning of a new phase in the methodologies of tool path interpolation. The tool path would no longer be represented through the use of elementary geometric elements (straight lines and arcs), as occurs in linear and circular interpolation, but by segments of curves (C0, C1, ..., Cn) based on the mathematical models used by the CAD system in the representation of complex surfaces. With this, CAM systems can determine a smoother and more precise tool path that can be adapted to the tolerance limits of the CAM system (see Figure 4).

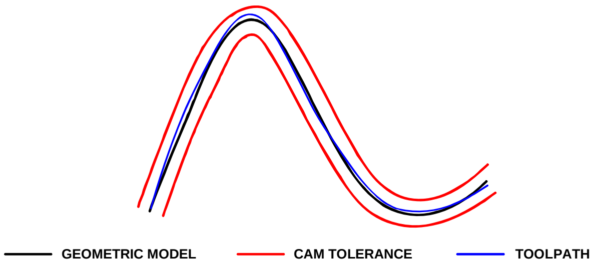


Figure 4. Polynomial interpolation representation

In the case of polynomial interpolation, these curves are defined by a polynomial function of degree 3 or 5, where the variables are the coefficients of the polynomial function and the p variable is the parameter of the generation of the curve, as illustrated in the following equations (Sinumerik 840D/840Di/810D, 2000):

$$f(p) = a_0 + a_1 \cdot p + a_2 \cdot p^2 + a_3 \cdot p^3 \tag{1}$$

$$f(p) = a_0 + a_1 \cdot p + a_2 \cdot p^2 + a_3 \cdot p^3 + a_4 \cdot p^4 + a_5 \cdot p^5 \tag{2}$$

The generated NC program no longer contains the G01, G02 and G03 commands of the ISO 6983 language, but rather a specific language for each numeric command that represents these polynomials.

## 2. Development of Machining Tests

To investigate the effect of tool path interpolation methodology in the manufacture of molds and dies, linear, circular and polynomial interpolation were used only in the finishing operation with CAM tolerance of 0,05 and 0,005 mm. In all tests the roughing and semi-finishing operations were identical.

The test model used in the machining tests as illustrated in Figure 5 is a part of a test model created by the NC-Gesellschaft, a German Association for the certification of machining centers (NC Gesellschaft Recommendation, 2000).

In order to simulate the manufacturing conditions for molds and dies, the manufacturing tests were done in AISI-SAE P20 steel provided by Aços Villares S.A..

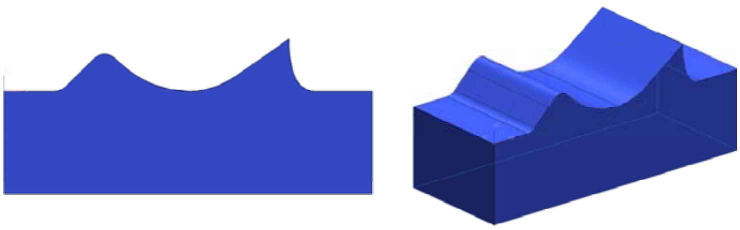

Figure 5. Test model used in experiments (NC Gesellschaft Recommendation, 2000)

The machining was done at the Romi Machining Center, Discovery 760 model, equipped with Siemens 810D command configured especially for the SCPM to develop research tests using complex methodologies of tool path interpolation (Polynomial, Spline and NURBS).

- rotation of tree axis (n): 10.000 $min^{-1}$;
- cutting speed ($V_c$): 502 m/min;
- feedrate ($V_f$): 5.000 mm/min.

A comparative analysis of tool path interpolation methodologies was carried out according to the following characteristics:

- machining time of test model;
- behavior of the real machining feedrate along the geometry of the test model;
- accuracy of the test model geometry in comparison with the geometric model developed by the CAD system;
- surface quality.

## 3. Analysis of the Results

### 3.1. Manufacturing Time

As can be observed in Figure 6, the polynomial interpolation presented better results with a reduction of 6% and 32% in relation to linear interpolation with a CAM tolerance of 0,05 mm and 0,005 mm, respectively.

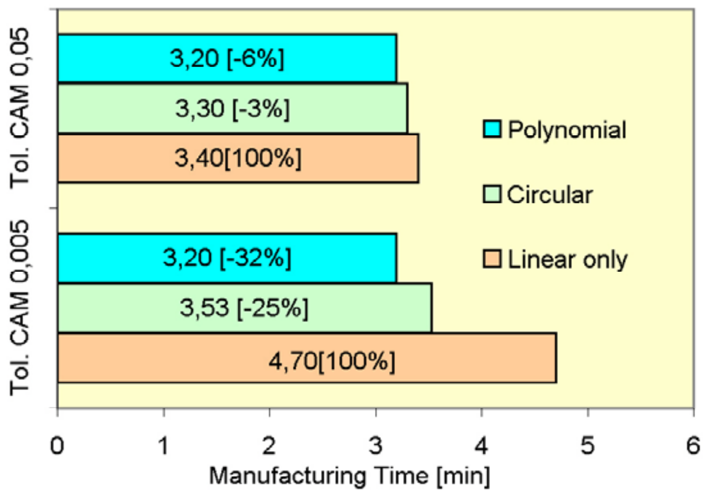


Figure 6. Manufacturing Time

In comparing the interpolation methodologies and the effect of the CAM tolerance, one can observe that:

- the polynomial interpolation, in which the tool path is represented by curve segments, does not show alterations in machining time in function of CAM tolerance;
- the reduction of machining time in function of tolerance could only be verified for linear and circular interpolations.

### 3.2. Performance of the Real Feedrate

Figure 7 and 8 show that despite the programmed feedrate of 5.000 mm/min, the real feedrate fluctuated along the geometry of the test model. Also, different characteristics were found among the tool path interpolation methodologies.

This reduction in real machining feedrate occurred primarily in function of the programmed segment size and the block processing time (BPT) of the machine tool.

For linear, circular and polynomial interpolation the programmed segment size for each of the NC programs was determined and compared with the real rate of machining.

Equation (3) supplies the estimate of the maximum feedrate in function of the processing time and of the size of the movement segment (Arnone, 1998).

$$V_f = \frac{\Delta x}{BPT/60} \tag{3}$$

Through this equation, it is possible to obtain the size of the minimum segment for a certain feedrate and to compare it with the size of the segments contained in the tool path of the NC program.

Considering a feedrate of 5.000 mm/min ($V_f$) and a block processing time of 12 ms, calculated through preliminary tests, it is possible to determine the size of the minimum segment equal to 1 mm ($\Delta x$).

From this, one can observe that in all cases, the linear interpolation shows a higher reduction in real feedrate in relation to other interpolations, resulting in a lower mean feedrate and, consequently, a longer machining time. On the other hand, the polynomial interpolation shows less reduction in real feedrate, resulting in a shorter machining time.

In relation to the effect of CAM tolerance on the methodologies, no reduction on real feedrate was observed in the polynomial interpolation due to the influence of CAM tolerance since there were no significant alterations in the programmed segment size for either CAM tolerance.

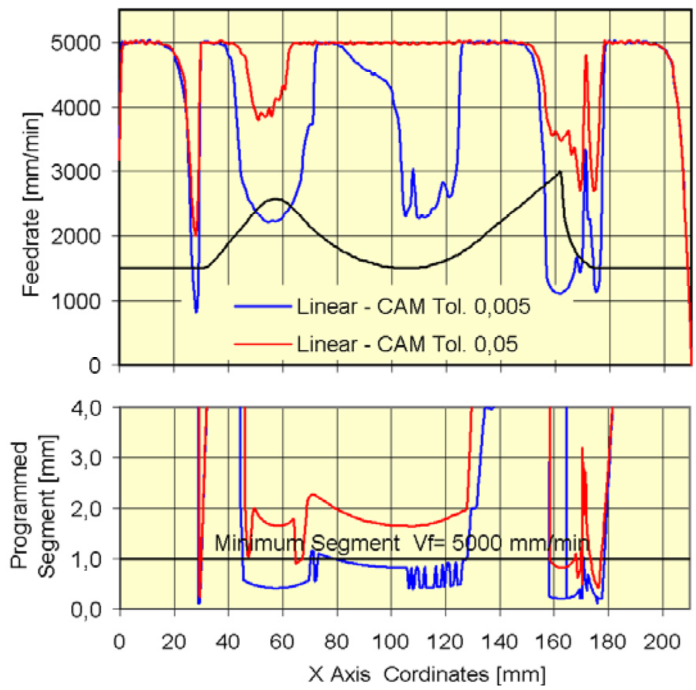


Figure 7. Performance of the real feedrate - Linear Only (Black line: CAD geometry)

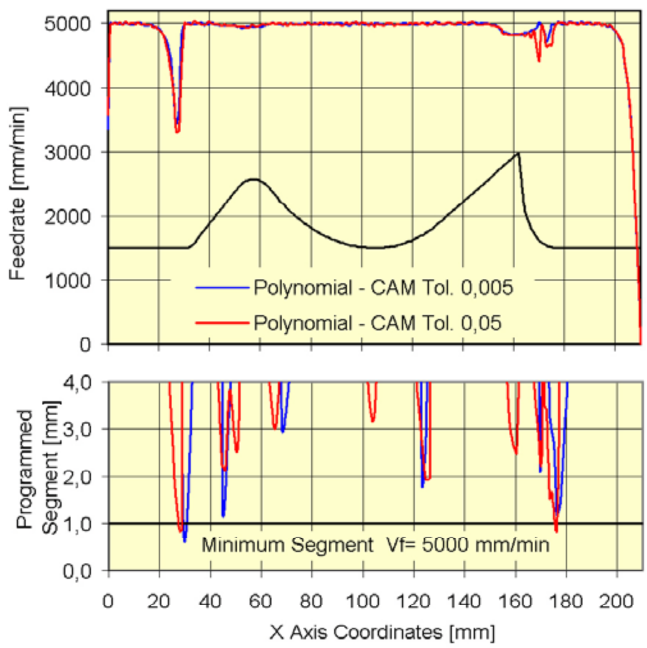


Figure 8. Performance of the real feedrate - Polynomial (Black line: CAD geometry)

### 3.3. Geometric Accuracy of the Machined Part

Figure 9 illustrates the values of geometric accuracy obtained with the tool path interpolation methodologies.

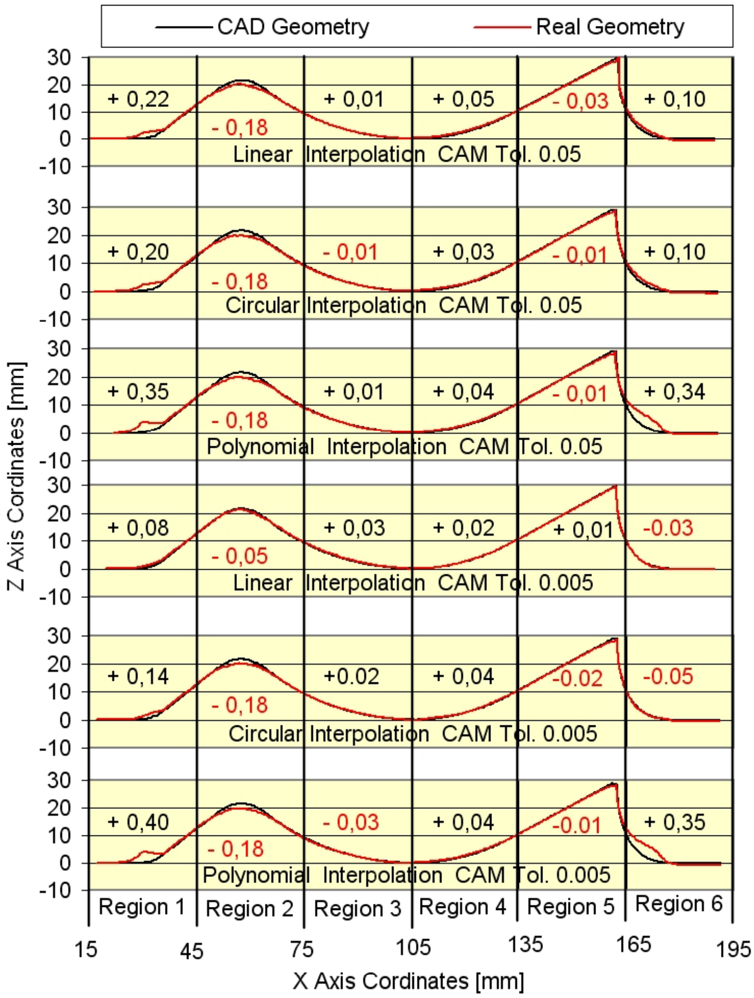


Figure 9. Geometric accuracy of test part

These results show that:

- for regions 1 to 6, all of the interpolation methodologies present a real geometry with outward deviation displacement in relation to the CAD model. Among these methodologies, the polynomial interpolation showed the highest variation and the linear interpolation showed the lowest variation, especially with a CAM tolerance of 0,005 mm;
- in region 2 all of the interpolation methodologies show a real geometry with inward deviation displacement in relation to the CAD model. Similar geometric variations of around 0,18 mm appeared in all of the methodologies with the exception of linear interpolation with a CAM tolerance of 0,005 mm, which showed a variation of around 0,05mm;
- regions 3, 4 and 5 presented a real geometry similar to the CAD model for all of the interpolation methodologies. The variation of the real geometry at the end of region 5 was disregarded due to lack of a good contact region for carrying out the measurement.

### 3.4. Surface Aspect

By measuring the test model roughness, it was possible to observe that:

- all of the tool path interpolation methodologies presented roughness values inferior to 0,50 µm Ra;
- variations of CAM tolerance in the interpolations did not affect surface roughness.

In addition to the roughness measure, a comparison of superficial aspects was carried out where it was possible to observe a “faceted” aspect on the complex machined surfaces with Linear and Circular interpolation.

## 4. Conclusion

Based on the results obtained, the following conclusions can be drawn:

- the CAM tolerance used in the generation of the tool path influences the performance of the tool path interpolation methodologies in different ways. While for Linear Only and Circular Interpolations a reduction in CAM tolerance results in a significant increase in machining time and in a reduction in deviance from the real geometric model, in Polynomial Interpolation the variation in tolerance significantly influenced only the surface aspect. This occurred because Linear and Circular Interpolation use a large quantity of small straight line segments to represent complex surfaces with small CAM tolerance ranges;
- Linear Interpolation was shown to be a more precise methodology primarily when there was a reduction in CAM tolerance. However, the generation of straight line segments smaller than the minimum established for the processing time of the machine tool and the faceted surface aspect in complex surfaces makes this methodology a limitation in the high-speed manufacture of molds and dies;
- Polynomial Interpolation has become one of the solutions for the manufacture of molds and dies, due to its performance in relation to machining time. However, high deviance in accuracy related to a faster machining feedrate and, consequently, a higher demand for dynamic behavior of the machine tool, can compromise the subsequent steps of adjustment and polishing of the mold, causing an increase in the lead time of the product;
- Circular Interpolation by showing a better performance in machining time and in accuracy of the real geometric model when compared to Linear and Polynomial Interpolations, as well as a better surface aspect when a greater CAM tolerance is applied can be considered a solution in the search for optimizing the manufacturing process of molds and dies. However, because it also uses straight line segments to represent the tool path, it presents the same problems of Linear Interpolation in the manufacture of molds and dies. This makes it also a limitation in the high-speed manufacture of molds and dies.

The objective of studies on tool path interpolation methodologies is the manufacture of molds and dies with the HSC technology. Results demonstrate that even when machining at feedrates within the transition range for HSC Technology there are limitations in the application of Linear Interpolation as well as benefits that can be found with the use of other interpolation methodologies.

## 5. Acknowledgments

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## 6. References

Arnone, M., 1998, High performance machining, Hanser Gardner Publications, Cincinnati, USA.
Altintas, Y., Erkorkmaz, K., 2003, Feedrate optimization for spline interpolation in high speed machine tools, Annals of the CIRP, 52/1:297-302.
Koninckx, B., Van Brussel, H., 2002, Real Time NURBS interpolation for distributed motion control, Annals of the CIRP, 51/1:315-318.
Langeron, J.M., Duc, E., Lartigue, C., Bourdet P., 2004, A new format for 5-axis tool path computation using Bspline curves, Computer-Aided Design, 36:1219-1229.
Lartigue, C., Tournier, C., Ritou, M., Dumur, D., 2004, High-performance NC for HSM by means of polynomial trajectories, Annals of the CIRP, 53/1:317-320.
NC Gesellschaft Recommendation, 2000, Milling Cutters and Machining Centers, NCG2004/Part1.
Sinumerik 840D/840Di/810D, 2000, Programming Guide Advanced.
Yau, H.T., Kuo M.J., 2001, NURBS machining and feed rate adjustment for high-speed cutting of complex sculptured surfaces, International Journal of Production Research, 39/1:21-41.