SINUMERIK System 800
Spline Interpolation

User Documentation

Programming Guide

Edition 12.88

SINUMERIK® Documentation

Key to editions

The editions listed below have been published prior to the current edition.

The column headed ”Amendments” lists the amended sections/pages with reference to the previous edition.

Edition	**Order No.**	**Amendments**
12.88	6ZB5 410-7BA02-0BA1	New edition

Contents

1 Introduction

1.1 What is spline interpolation?

The spline interpolation method described in this Guide is used to connect **a small number of spline points on a set contour with smooth curves**. The individual curve segments are adjoined with the same slope and the same curvature in each case. This results in **smooth** transitions, thus reducing wear and tear on machine tools. By setting the spline points very close to each other, almost sharp edges can be programmed. Even critical sequences of spline points do not cause overshooting.

The spline interpolation method described in this Guide allows a **significant reduction of NC blocks when working on complex workpiece geometries**, which is a great advantage compared with spline functions using standard methods. The more complex the surface to be machined and the higher the quality requirements are, the shorter the contour segments described by an NC block become. For numerical controls that use only linear interpolation, this can lead to an immense amount of data which can hardly be processed. The greater the number of elements which can be programmed and interpolated **directly**, however, the smaller is the number of NC blocks required to machine arbitrary curve paths. Spline interpolation supplies this set of contour elements. The reduced number of NC blocks allows a higher feedrate and thus economical production. **The working examples in this Guide show how powerful the method is.**

The spline interpolation method is made up of two components: the so-called TRANSLATOR, a program which translates linear NC blocks into spline blocks, and the INTERPOLATOR, which is a function in SINUMERIK controls. Additional knowledge is not necessary. NC programmers create their programs in the usual way and the TRANSLATOR automatically translates the programs into the correct format, which can be interpreted by the INTERPOLATOR.

The spline interpolation method can be applied in the following areas: high-speed and high-precision machining of complex contours, 5-axis milling, machining of free form surfaces, woodworking, laser and plasma machining processes.

1.2 What is a spline?

A spline is a smooth curve, i.e. a curve without any edges and with constantly changing radii of curvature. A spline is made up of a series of 3rd degree polynomials.

Example:

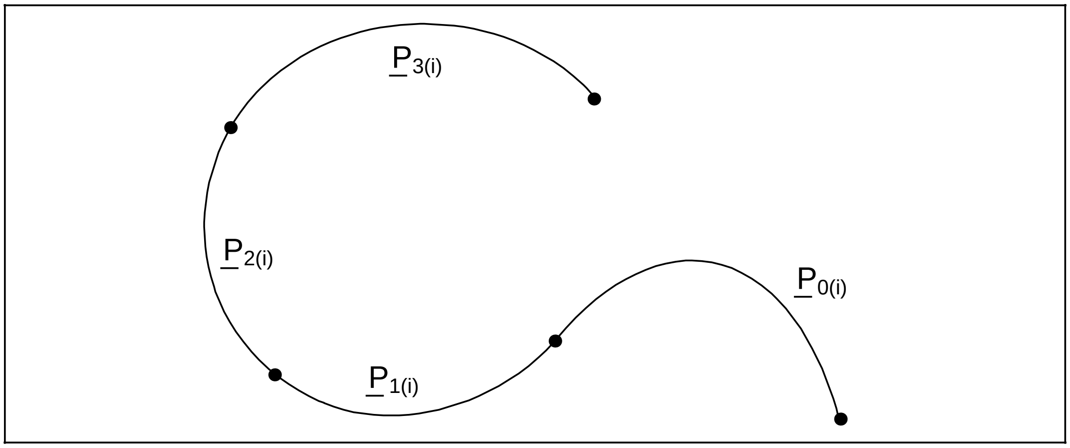

Fig.1.1 Spline made of four segments in the x,y plane

Notes for readers who are interested in mathematics:

The spline in Fig. 1.1 is described by the four spline segments $\underline{P}_0$, $\underline{P}_1$, $\underline{P}_2$ and $\underline{P}_3$. Each spline segment P is characterized by a 3rd degree polynomial P_{nx} and a 3rd degree polynomial P_{ny}.

$$\underline{P}_n = \begin{cases} P_{nx}(i) \\ P_{ny}(i) \end{cases}$$

The polynomials P_{nm} (m = x, y) are functions of the path parameter i:

$$P_{nm}(i) = A_{3m} * i^3 + A_{2m} * i^2 + A_{1m} * i + A_{0m}$$

Each position within a spline segment is defined by the path parameter i which is equivalent to the path length to be covered from that position to the end position.

The reason why splines are described by 3rd degree polynomials is as follows:
As already mentioned above, the aim of spline interpolation is to join curve segments of various slopes and curvatures by smooth transitions. 1st degree polynomials describe only curves which have a constant slope, i.e. straight lines. Thus smooth transitions between straight lines of different slopes cannot be produced with 1st degree polynomials. 2nd degree polynomials have a variable slope, but the curvature is constant. 3rd degree polynomials join curve segments of various slopes and various curvatures by smooth transitions, whereas polynomials of higher degrees tend to produce oscillations, which means that the quality of the transitions is not improved.

1.3 What is the approximation method?

In this text, the approximation method relates to the computation of 3rd degree polynomials (i.e. splines), using specific spline points of a set contour. The splines can differ from the specified points by a selectable amount. Two different approximation methods can be applied.

With the **standard spline method**, a spline segment is calculated from two points and two boundary conditions.

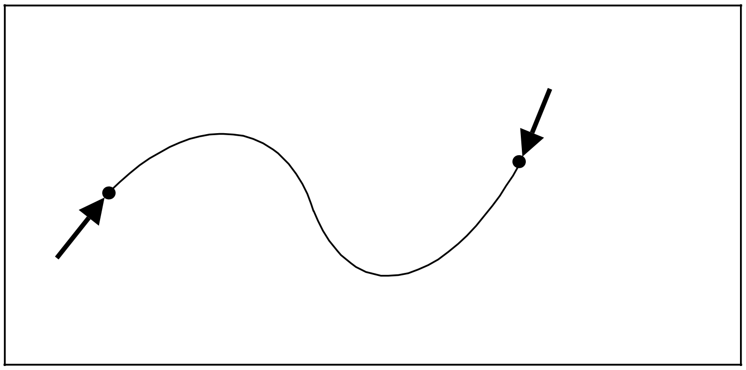

Fig. 1.2 The standard spline method

With the so-called **Newton Method of Approximation** a spline segment is calculated from four points.

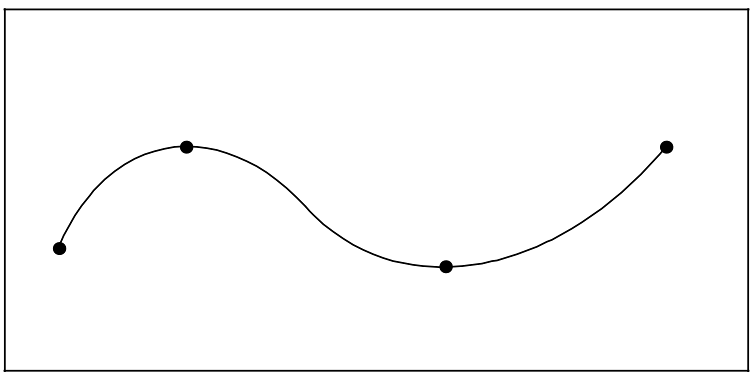

Fig. 1.3 The Newton method of approximation

For working examples of these methods please refer to Section 3.

1.4 What is data reduction?

Using data reduction methods, spline interpolation can transform a large number of linear blocks into just a few spline blocks.
The example in Fig. 1.4 shows how seven linear blocks are replaced by one spline block (a **reduction factor** of 7).

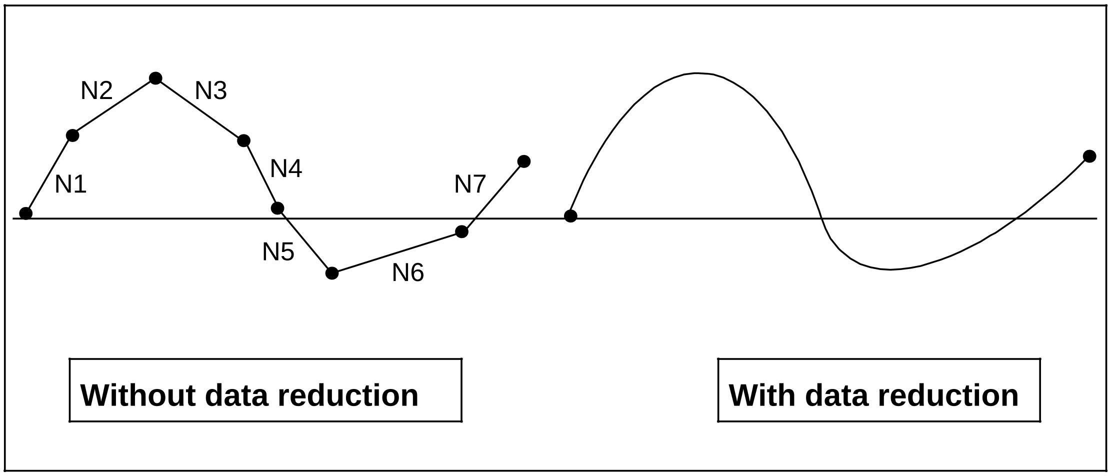

Fig. 1.4 Data reduction: Seven linear blocks can be replaced by one spline block

The method in detail:
A tolerance field is defined around the set contour. The width of the tolerance field corresponds to the preset **tolerance value**. If this value is exceeded when the spline is computed (i.e. the deviation of the spline from the set contour has reached the permissible tolerance limit), the approximation run automatically generates the next spline block. The width of the tolerance field therefore affects the accuracy of the contour and hence the number of computed spline blocks. The more accurately the contour is to coincide with the set contour, the narrower must be the width of the tolerance field .

The graphical example in Fig. 1.5 shows that the width of the tolerance field also affects the number of points which suffice to accurately describe the contour within the required tolerance.

The wider the tolerance field is, the fewer the number of points that are needed to describe the contour. If a minimum of data is specified to describe the contour with the given tolerance, the data stream is said to be **coarse**. Alternatively, if more data is specified than is required for the description, the data stream is said to be **fine**.

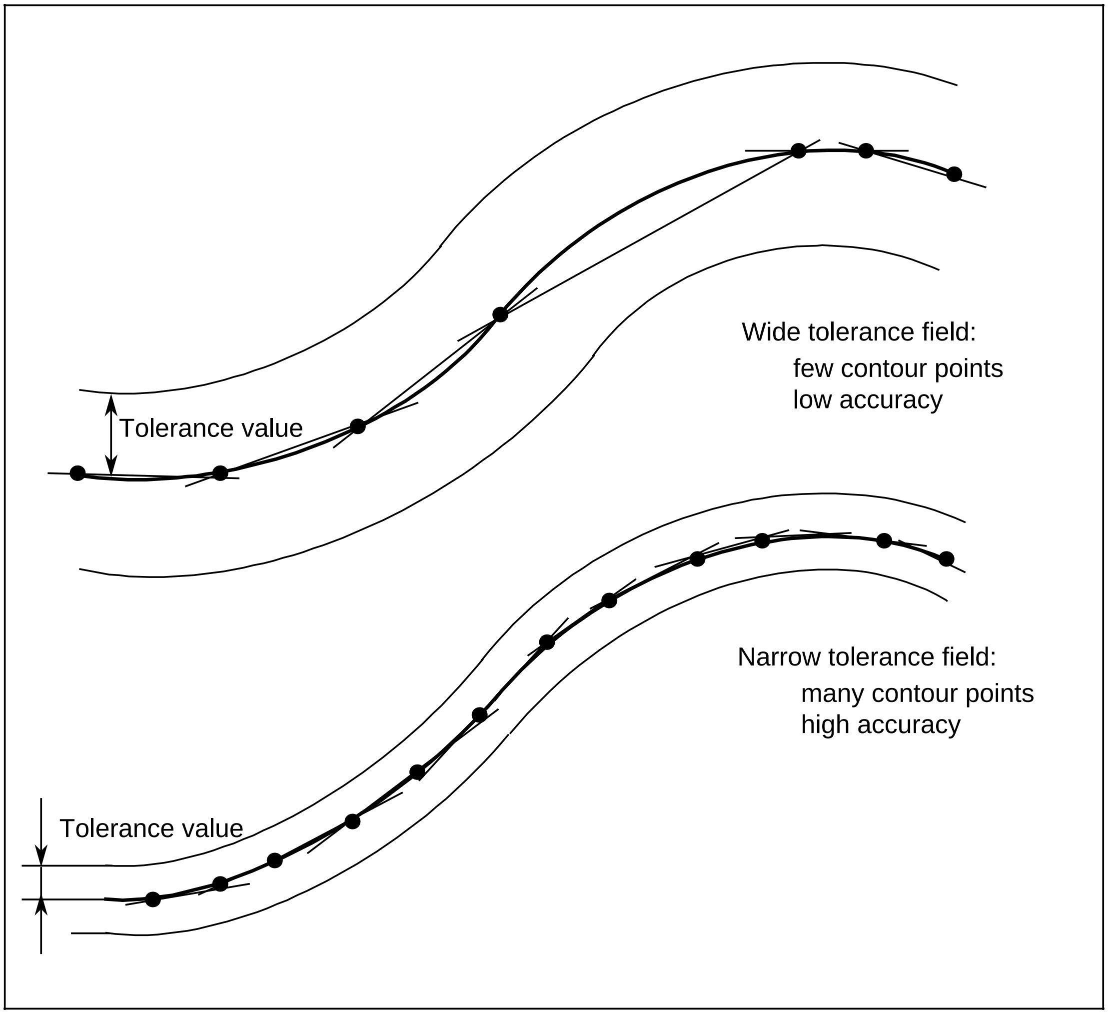

Fig. 1.5 Approximation with a wide and a narrow tolerance field

The tolerance value can also be ”zero”. In this case, the splines to be computed may not deviate from the given contour points.

Depending on the approximation method chosen, data reduction can still occur even in this case.

Due to its algorithm, the Newton Method of Approximation causes data reduction by a reduction factor of 3 because a spline segment is computed from four points and the fourth point of the first spline segment is identical with the first point of the second spline segment.

Due to the algorithm of the Standard Spline Method, however, no data reduction occurs because it computes a spline between two points.

2 Applications

Spline interpolation opens up new possibilities for the user, especially in the following areas of application:

- **High-speed and high-precision machining of complex contours**
  In high-speed and high-precision machining of complex contours, the same basic problem can occur in each case, namely that the time for processing a block becomes extremely short when programming in the conventional way. In high-speed machining, this results from the fast rate at which NC blocks are processed, and in high-precision machining of complex contours it is due to the extremely short block lengths.
  Spline interpolation provides solutions to these problems because the higher degree of interpolation significantly extends the traverse described by one block. In other words, fewer blocks are needed to describe any contour. The smooth transitions between the contour segments preclude sudden changes of acceleration. This reduces wear and tear on machine tools.
  A working example (camshaft) is described in Section 3.4.2.

- **5-axis milling**
  The programming of five machine axes using conventional geometries results in large quantities of data. At the feedrates which are technologically necessary and economical, such quantities cannot always be processed completely within the block cycle times prevailing at present. Spline interpolation and data reduction can reduce the number of blocks significantly and thus increase the feedrate.

- **Machining of free form surfaces**
  Spline interpolation enables machining of surfaces which cannot be described by standard geometries. The necessity to produce these free form surfaces for automobile parts and injection moulded parts for consumer goods results from a combination of aesthetical and functional viewpoints. Free form surfaces are also needed for aircraft construction and shipbuilding because these surfaces are difficult to describe analytically. The number of blocks which were previously necessary to machine such complex workpiece geometries can now be reduced considerably since the introduction of spline interpolation, because larger path sections can be described by fewer spline points and therefore fewer NC blocks. A working example (phone receiver) is described in Section 4.2.

- **Woodworking**
  The description of high-speed machining problems above also applies to the machining of wood. The high speed of the cutter requires very high feedrates. If the feed suddenly drops to zero, there is a risk of the cutter burning loose. A working example of 5-axis cutting in woodworking (backrest of a chair) is given in Section 4.1.

- **Laser and plasma machining**
  Cutting and welding technologies. Laser cutters must be positioned normal to the surface to avoid burrs. This means applying 5-axis machining to curved sheet metal parts. Apart from the geometry the laser intensity can also be controlled.

3 The Method

The spline interpolation method consists of

- **recording the contour**
- **approximation method (TRANSLATOR)**
- **spline interpolation**

The procedure is shown in the diagram below:

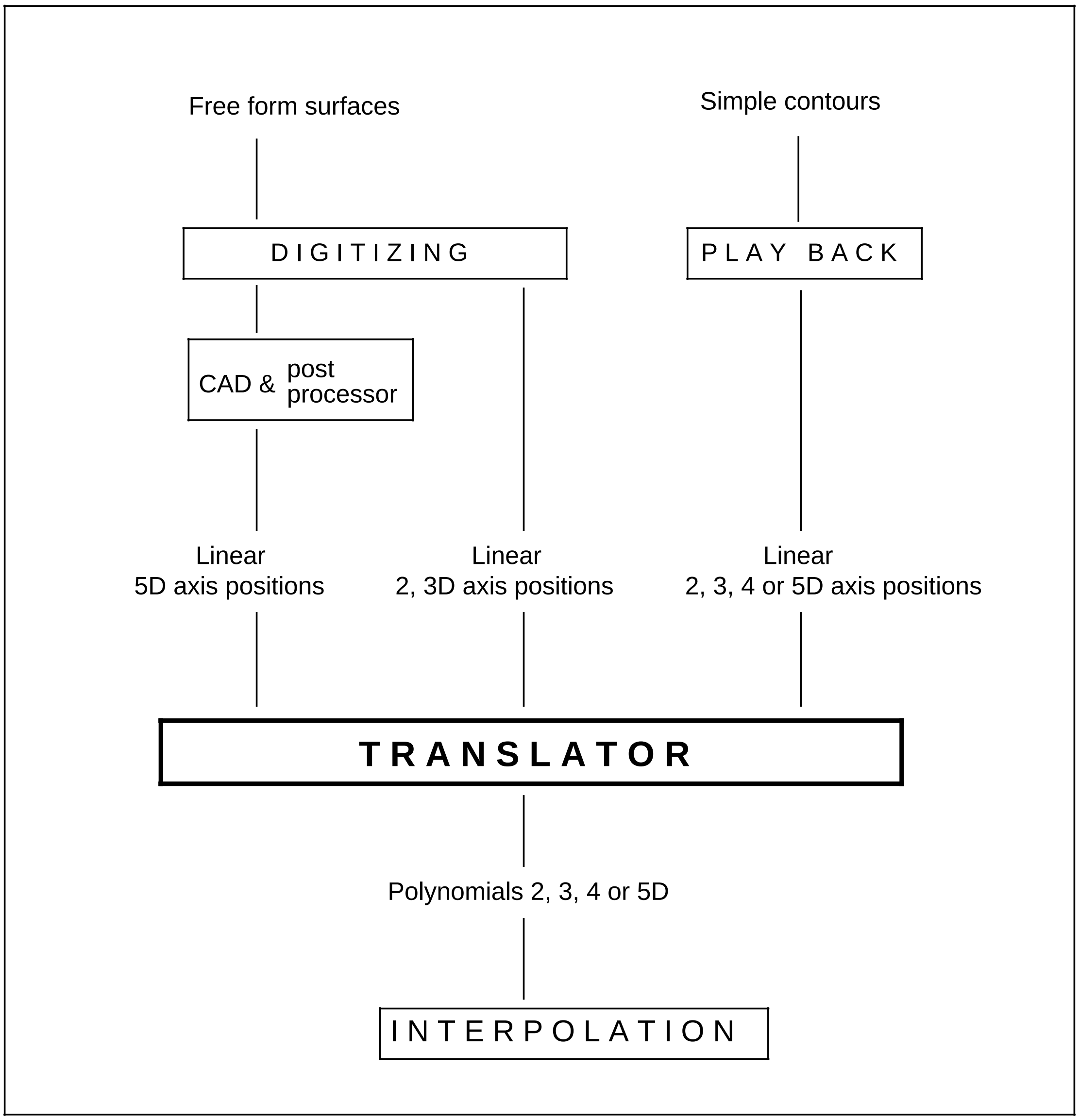

Fig. 3.1 The entire spline interpolation procedure

The various steps of the procedure, in particular the application of the approximation software (TRANSLATOR), are explained in detail in the following sections.

3.1 Recording the contour

The contour can be recorded using the following options:

- Play Back
  ”Play Back” is a programming method in which the machine tool is driven to different contour points on a master workpiece in the conventional traversing mode. The axis positions of the machine axes can then be transferred to the part program memory. The resulting part program can then be modified or completed and be used to produce further identical workpieces.

- Digitizing
  A scanning device obtains the contour geometry data.The acquired 3D coordinates are either used directly as linear 3D axis positions or converted to linear 5D axis positions by means of a postprocessor.

- CAD programming systems
  e.g. NC 800 -- a programming system for two-dimensional machining.

3.2 Approximation using the TRANSLATOR

The approximation method and handling of the TRANSLATOR (a program for generating spline blocks from standard NC programs) will first be described in general terms. The configuration of the TRANSLATOR is described at the beginning because the programmed axis designations and the machine geometry must be specified before starting the approximation procedure.

Following the description of the approximation method the application of the TRANSLATOR is shown for the following examples:

- Creating a smooth curve from a small number of spline points
- Creating a small number of NC blocks from a large number of linear blocks

3.2.1 Configuration for the approximation method

Before starting the approximation method, the designation of the programmed axes must be declared.

The milling head type used must also be known before the approximation starts because the tool length compensation depends on it.

These can both be entered after selecting the function ”Configuration” in the main TRANSLATOR menu.

To obtain the menu, TRANSLATOR must be called by typing the command **translat** followed by hitting RETURN.

After pressing any key, the main menu is displayed:

Approximation
Data trans. PC NC
Data trans. NC PC
Return to MSDOS
Configuration

Fig. 3.2 TRANSLATOR main menu

Select the function "Configuration" in this menu. (The selected function is highlighted. You can move to the other options by using the space bar, the arrow keys, or the RETURN key.)

After pressing the F2 function key, the following screen form is displayed:

Configuration

Models of 5-axis machine:
1: Nutating head — Fixed head angle: 45.000
2: Gimbal head
3: Twist and nod head
4: Inclinable head
Enter your choice: ______ 1
Axis names:
Linear axes: 1: X 2: Y 3: Z
Rotary axes: 1: B 2: C
Error constant rotary axis 1 : 1.000
Error constant rotary axis 2 : 1.400
<F1> Last screen page
<F2> Start execution
<F4> Stop execution

Fig. 3.3 Configuration screen form

To make it easier to select the cutter head type, these are shown below diagrammatically and information on the axis constellation is given.

Note:

The two constants in the screen form are:

- for 5-axis machines, model 1
  Error constant rotary axis 1: 0.017
  Error constant rotary axis 2: 0.024

- for 5-axis machines, models 2, 3, 4
  Error constant rotary axis 1: 0.017
  Error constant rotary axis 2: 0.017

Having entered the data, the screen form is exited by pressing F1 or F2 and a return is made to the main menu.

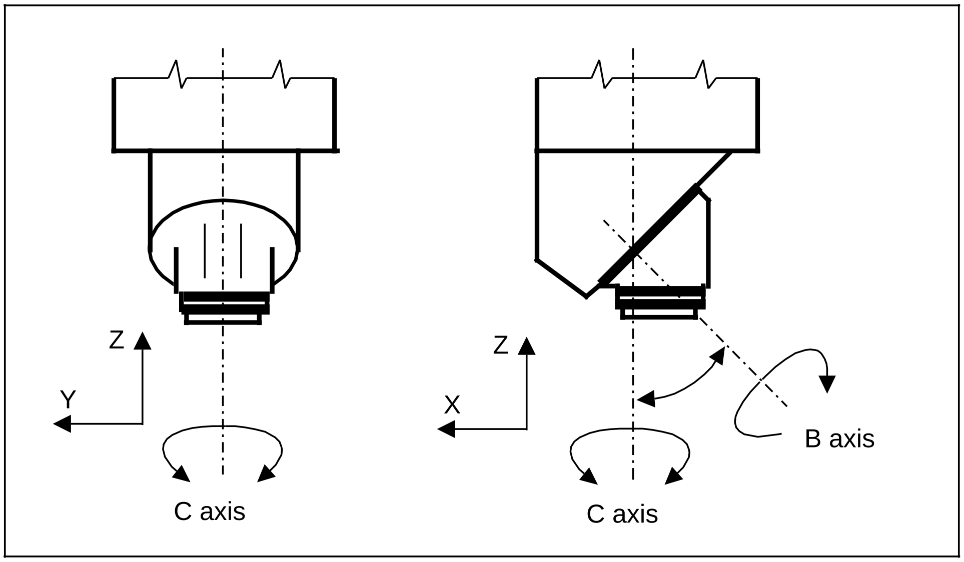

Fig. 3.4 Nutating head

The tool is parallel to the Z axis when B = C = 0.
The B axis is in the X-Y plane when C = 0.

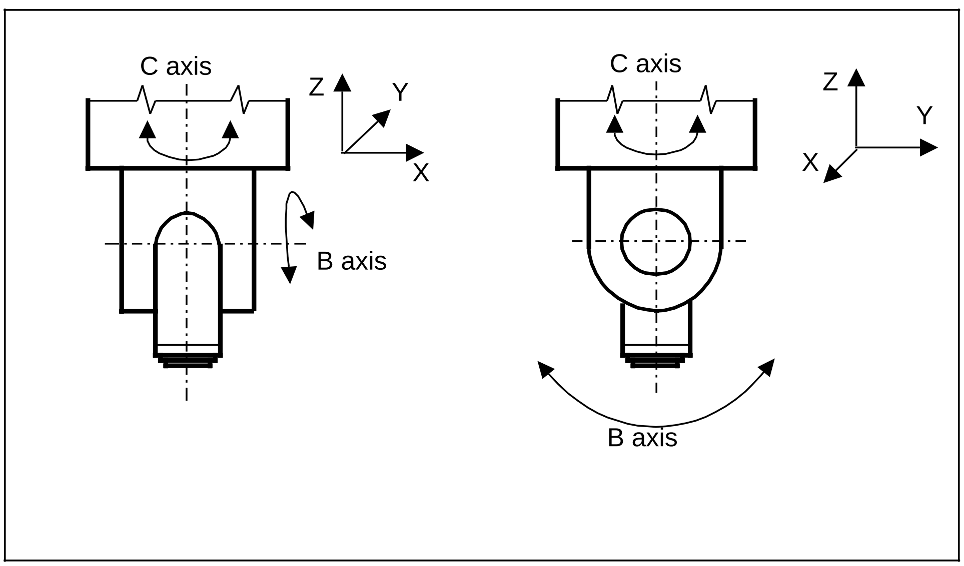

Fig. 3.5 Gimbal head

The B axis is along the Y axis when C = 0.
The tool is parallel to the Z axis when B = 0.

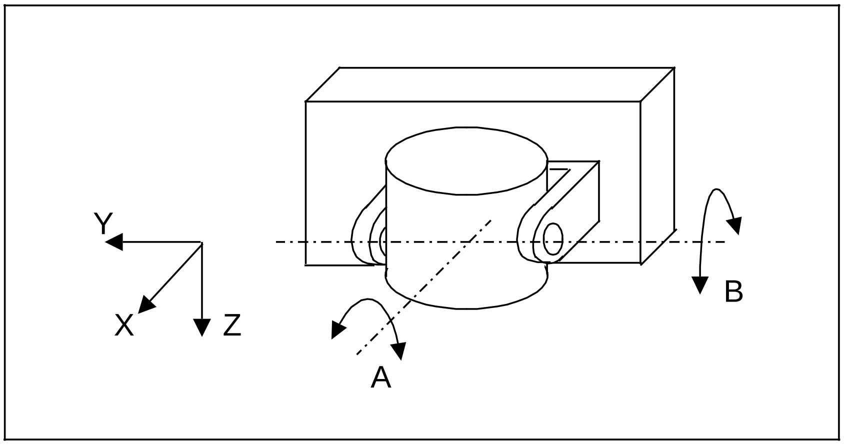

Fig. 3.6 Twist and nod head

The tool is parallel to the Z axis when A = B = 0.
The A axis is always about the X axis.
The B axis is about the Y axis when A = 0.

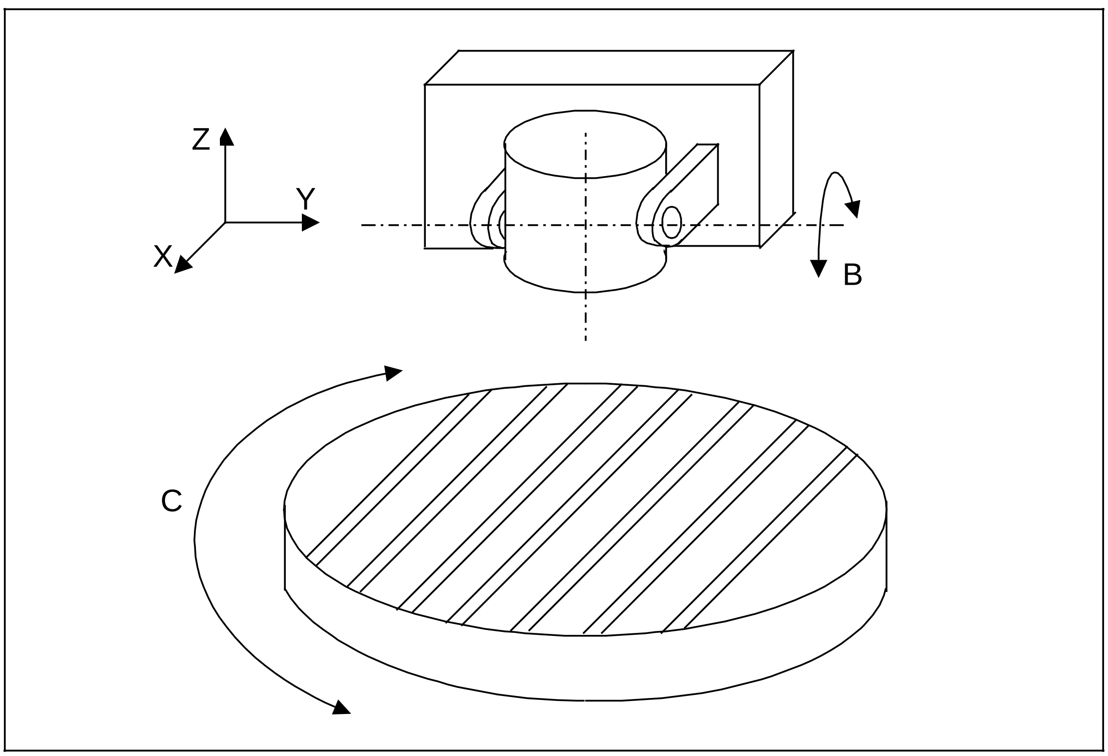

Fig. 3.7 Inclinable head

The rotary table (axis C) rotates about the Z axis.
The swivel head (axis B) rotates about the Y axis.
The range of swivel about B is usually between -45° and +45°

3.2.2 Operating the TRANSLATOR

- Edit the standard NC program in a file named **prog**xxxx.dat (”xxxx” represents any program number with up to four digits.)

  When creating this program, the following conditions must be observed:

  a) Up to 5 axes can be programmed.

  b) The program may contain Help functions and comments, but no tool compensation may be programmed.

  c) Only absolute dimensions are allowed.

  d) The NC blocks may be written with or without block numbers.

  e) Note that the axis names in the program must correspond to the axis names chosen in the configuration procedure (see Section 3.2.1)

  f) All five axes must be specified before the first program section to be translated into spline blocks.

  Note:

  Before starting the approximation procedure, check if the labels of the five programmed axes correspond to the configuration data of the TRANSLATOR (for more details on configuration see Section 3.2.1)

- Mark the beginning of the linear blocks to be converted to spline blocks with the additional functions **M50** and the end with **M51**.
  Alternatively, the relevant block numbers can also be written into a file **can**xxxx.**dat**, where ”xxxx” represents the program number selected above.

- Call the TRANSLATOR with the **translat** command and press RETURN.

- After pressing any key, the TRANSLATOR main menu is displayed.

- Select the ”**Approximation”** function in the menu. (The selected function is highlighted. Other options can be selected by using the space bar, the arrow keys, or the RETURN key.)
  After pressing the F2 function key, the screen form for the approximation procedure is displayed.

- Select the required approximation method and, where applicable, enter the tolerance value for the endpoints of the spline segments.

  Method 1: Newton's approximation method
  Method 2: Newton's approximation method with boundary conditions
  Method 11: Dynamic natural splines
  Method 12: Dynamic natural splines with data reduction

The four approximation methods are:

Method	Boundary conditions	Appropriate data stream *	Reduction factor	Contour/surface quality
1	Continuous	Very fine	Very high	Smooth
2	Continuous & differentiable	Fine - coarse	High	Smooth
11	Continuous & 2x differentiable	Coarse	None	Very smooth
12	Continuous & 2x differentiable	Very fine - coarse	High	Very smooth

* The term "data stream" is explained in Section 1.4.

The following methods were used for the working examples in this Guide (see Sections 3.4 and 4):

	Application	Method
Phone receiver	Roughing Finishing	1 12
Backrest of chair		11, 2
Shoe sole		11, 2

- Choose the procedure for checking the tolerance criteria. If procedure 1 (general) is chosen, the positions of the five axes on the spline are checked during approximation, the configured machine geometry and the tool length being taken into consideration. If procedure 2 (axis-specific tolerances) is chosen, the positions on the spline are checked for each of the programmed axes.

  Procedure 1 should be chosen, whenever the program to be translated is

  a) a 5-axis program for one of the four programmable machine geometries (for more details see Section 3.2.1)

  b) a program for 2 or 3 linear axes. (Any rotary axis tolerances entered in the screen form are not considered.)

Procedure 2 is advisable in all other cases, in particular if the machine tool has rotary axes, but cannot be configured by any of the four geometries.

- Press F2 for page 2 of the screen form.

- Enter the number of the part program and of the spline program. After entering the number of the part program, the same number is entered automatically for the spline program after pressing RETURN. If a part program is to be translated using different approximation methods, a different number must be chosen for each spline program, otherwise it would be overwritten each time.

- Enter the value for tool length. If a part program is to be translated in which five machine axes have been programmed, and if the general tolerance criterion has been selected, the tool length for which the five axis program was created must be entered here.

- Enter the value for tool length compensation. The tool length compensation corrects the programmed block endpoints according to the type of milling head.
  Before starting the approximation procedure, the milling head type used must be specified in the screen form of the ”Configuration” function (for more information see Section 3.2.1).

- Enter the tolerance values for the endpoints of the spline segments.
  (In Method 1 ”Newton's approximation method”, it is also possible to enter tolerance values for the midpoints of the spline segments. In Method 11 ”Dynamic natural splines” no tolerance values are required.)

- Enter values for the maximum deviation on the rotary axes.
  (In Method 11 ”Dynamic natural splines”, no tolerance values are required.)

- Press F2 to start the approximation procedure.
  Online messages displayed on the screen allow the progress of the procedure to be observed. The approximation speed of complex programs can be increased by simultaneously pressing the ”CTRL” and ”O” keys to switch off the display of the messages. Message display is reactivated by pressing these keys again. The ”Program executed with success” message indicates the end of the procedure and the main menu is displayed. The approximation procedure can be interrupted and terminated by pressing ”CTRL B”.

- The system writes the generated NC program with the spline blocks to the **spln**xxxx.**dat** file, where ”xxxx” represents the spline program number. The header of the spline program contains information on the program numbers of the part and spline programs, the chosen approximation method and the tolerance values.

  Note:

  When the spline program has been edited, it should not be edited further. In particular, the spline points in the spline blocks should not be changed.

3.2.3 Data transfer

To transfer data from the PC to the NC unit and vice versa, the appropriate functions must be selected in the TRANSLATOR main menu.

After pressing F2, a screen form appears in which the number of the program to be transferred must be entered.

Notes:

The receiving device must be started first before transferring data.

The data transferred from the NC unit to the PC is written into the current MSDOS directory that has been specified. The TRANSLATOR addresses the serial interface by the name LPT1:.

For more information on the transfer of programs from NC to PC please refer to the ”TRANS-PCIN/TRANS-PGIN” User's Guide.

3.3 Spline interpolation

For the method described here, the control must be equipped with the appropriate interpolator.

The spline function can be executed

- with constant tool path feedrate
- with deceleration and acceleration on the spline
- with effective override switch.

Some of the contour elements which can be created using spline interpolation:

- Solid circle
- Ellipses
- Sinus function
- Exponential function
- Root function

3.4 Working examples of the approximation method

Application of the TRANSLATOR will be demonstrated below for the following examples:

- Creation of a smooth curve using a small number of spline points
- Creation of a small number of NC blocks using a large number of linear blocks

3.4.1 Creation of a smooth curve using a small number of spline points

The contour of a shoe sole has been chosen as working example for creating a smooth curve using a small number of spline points.

The spline points for the contour are taken from a drawing. A flexible ruler can be used to do this. The spline points are those points where the flexible ruler must be held in position in order to follow the contour. In this example, 10 spline points are needed.

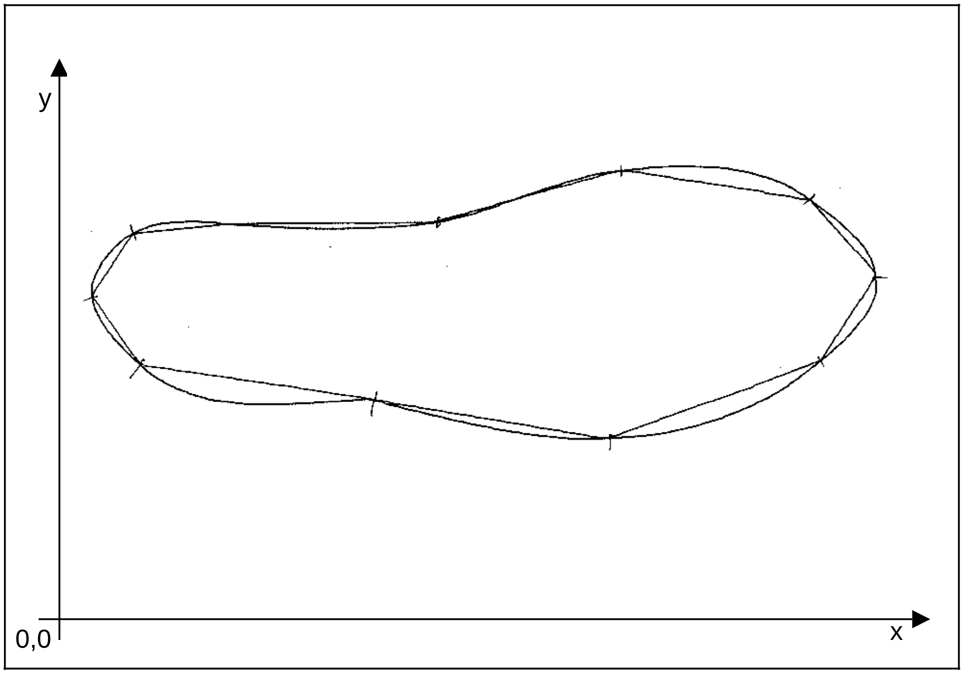

Fig. 3.8 Spline points of the shoe sole contour

The file containing the NC program which consists of linear blocks must have the file name **prog**xxxx.**dat**, where ”xxxx” represents the given program number with up to four digits. The file must be named ”prog150.dat” for the following program example.

```
%MPF 150
N10   G10 G90 G01 G64 F5000 S3000 X0 Y0 Z0 B0 C0
N15   G00 X0.3 Y7
N20   G01 Y8 M03
N25   X1.8 Y10.2 M50
N30   X12.4 Y10.3
N35   X18.9 Y12
N40   X25.3 Y10.8
N45   X27.5 Y8
N50   X25.5 Y5
N55   X18.3 Y2.4
N60   X10 Y4
N65   X1.9 Y5.4
N70   X0.3 Y8 M51
N75   G00 X0 Y0 M04
N80 M30
```

The first and the last linear blocks to be translated are marked by the additional functions **M50** for the beginning and **M51** for the end of translation.

Alternatively, the relevant block numbers can be written into a second file with the name **cand**xxxx.**dat**. ”xxxx” must be replaced by the program number selected above. This approach is recommended to avoid editing in long NC programs. In our example, the numbers 25 and 70 must be entered in a file with the name cand150.dat.
(In the example: 25 70)

Having finished editing, TRANSLATOR is called by means of the command **translat** and the RETURN key to confirm the command.

After pressing any key, the TRANSLATOR main menu is displayed.

The function ”**Approximation”** must be selected in this menu. (The selected function is highlighted. Other options can be selected by using the space bar, the arrow keys, or the RETURN key.)

After pressing F2, the screen form for the approximation procedure is displayed.

First the required method must be entered. For the given example, Method 11 **”Dynamic natural splines”** is selected. (In Section 3.2.2 there is a list of all methods.)

As a rule, the procedure for entering the tolerance values must then be selected. Since Method 11 does not require any tolerance values, no further mention of this procedure is needed here.

By pressing F2, the second page of the screen form appears on the display.
First, the number of the program to be translated must be selected, i.e. 150 in our example. By pressing RETURN, the same number is also selected for the translated program.

Finally, the tool length and tool length compensation data must be entered. ”0” has been chosen for this example.

After all entries have been made, the approximation procedure is started by pressing F2. The message ”**Program executed with success”** indicates the end of the procedure and the main menu is displayed again.

The generated program containing the spline blocks, which was written into the new file with the file name **spln**xxxx.**dat**, can now be transferred from the PC to the NC.

This is done by selecting the function ”Data Trans. PC -> NC” in the main menu, and then by pressing F2. The number of the program to be transferred must then be entered in the screen form which then appears. Finally, the transfer is initiated by pressing F2 again.

To end the TRANSLATOR session instead of transferring the program on completion of approximation, the ”Return to MSDOS” function must be selected in the main menu or F4 must be pressed to return to the operating system.

The new program has the following format:

```
( Generated by Spline Translator Version 3.1 )
( Part program number:           150 )
( Spline program number:         150 )
( Algorithm for spline approximation: 11  Algorithm without data reduction)


%MPF 150
N10  G1    F5000  S3000  X0.000  Y0.000 Z0.000 B0.000 C0.000
N15  G0    X0.300 Y7.000
N20  G1    M03    Y8.000
N25  G6    X1.800 Y10.200       I2.663
     K276923492  K49414954    K-225794784
     K38297302   K-191418244  K-167662809
N30  G6    X12.400      Y10.300      I10.600
     K11225893   K-25162046   K-273457996
     K-48599505  K123939431   K-156045
N35  G6    X18.900      Y12.000      I6.719
     K-8685768   K11719673    K-257627379
     K7424660    K-160932804  K-35810248
N40  G6    X25.300      Y10.800      I6.512
     K48726705   K-147111344  K-208476154
     K20702915   K-173112563  K160909975
N45  G6    X27.500      Y8.000       I3.561
     K274008336  K-574498114  K-19668332
     K-80796360  K25073904    K230708998
N50  G6    X25.500      Y5.000       I3.606
     K-204549846 K-22884017   K238221946
     K-77085062  K152425968   K186129522
N55  G6    X18.300      Y2.400       I7.655
     K-3160504   K-3442601    K261214535
     K5298010    K81814280    K5468220
N60  G6    X10.000      Y4.000       I8.453
     K-607834    K213677      K264656498
     K20010451   K-28047248   K-64480693
N65  G6    X1.900       Y5.400       I8.220
     K-41066769  K164972938   K181672702
     K-68518720  K256316753   K-164935188
N70  G6    X0.300       Y8.000       I3.053
     K-424221812 K742351560   K-18130880
     K88108962   K39537514    K-267822451
N75  G0    M04    X0.000 Y0.000
N80  M30
```

It can be seen that a spline block defining a 2D spline segment consists of 3 blocks (1 coordinate block and 2 coefficient blocks) which the NC unit interprets as one block.

The following applies in the coordinate block:

N Block number
G6 G function for spline interpolation
X, Y Endpoint coordinates of the machine axes involved in the path
I Path length (value of the curve parameter at the beginning of the spline segment)

The following expressions are used in the coefficient block:

K Coefficients of the axis polynomials of 3rd degree.

The coefficient blocks are located in the same order as the axes involved in the path. Each of the coefficient blocks contains the coefficients of an axis polynomial in the order K_3, K_2, K_1. The coefficients K_0 do not occur because they coincide with the endpoint coordinates (coordinate block).

3.4.2 Creating a small number of spline blocks from a large number of short linear blocks (data reduction)

The following example of a cam contour shows how programs containing vast amounts of data can be reduced in size considerably by converting to a small number of NC blocks using the spline interpolation and data reduction methods.

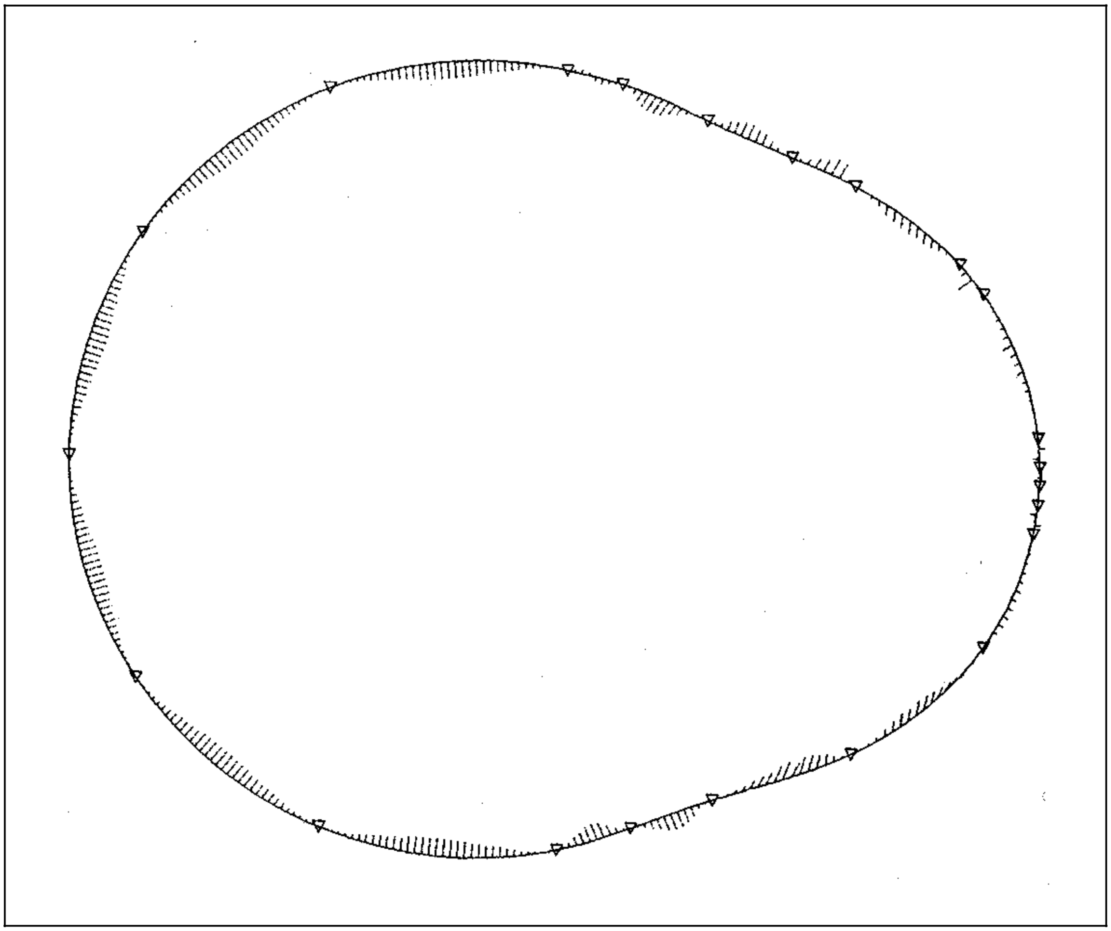

Fig. 3.9 Cam contour (deviations of computed spline segments from the ideal contour have been magnified 500 times)

The procedure:

- After starting the TRANSLATOR, transfer the NC program consisting of 360 linear blocks from the programming system to the PC.
- Call the approximation function.
- Specify the required approximation method. In this case, Method 12: ”**Dynamic natural splines with data reduction”**.
- Select procedure 1 (General) to enter tolerance values.
- Press F2 to display page 2 of the screen form.

- Enter the names of the part program and the spline program. After entering the number of the part program, press RETURN to automatically accept the same number for the spline program.

- Enter ”0” for the tool length and tool length compensation values.

- Enter the tolerance value for the endpoints of the spline segments (in this example, 0.01 mm).

- Start the approximation procedure by pressing F2.

- The approximation procedure with data reduction results in an NC program consisting of **18** (!) spline blocks with a tolerance of 0.01 mm. This is a reduction factor >20!

A comparison of a section of the part program and the corresponding section of the translated spline program clearly shows the effect of data reduction.

The first 65 linear blocks of the part program:

```
%MPF 2222
N00 G01 G90 G64 F10000   X0   Y0   Z0   B0   C0
N01   B94.0  X38.494
N02   B95.0  X38.492   M50
N03   B96.0  X38.495
N04   B97.0  X38.460
N05   B98.0  X38.420
N06   B99.0  X38.375
N07   B110.0 X38.325
N08   B111.0 X38.269
N09   B112.0 X38.209
N10   B113.0 X38.144
N11   B114.0 X38.075
N12   B115.0 X38.009
N13   B116.0 X37.092
N14   B117.0 X37.835
N15   B118.0 X37.745
N16   B119.0 X37.649
N17   B120.0 X37.549
N18   B121.0 X37.445
N19   B122.0 X37.335
N20   B123.0 X37.222
N21   B124.0 X37.102
N22   B125.0 X36.975
N23   B126.0 X36.845
N24   B127.0 X36.713
N25   B128.0 X36.572
N26   B129.0 X36.425
N27   B130.0 X36.274
N28   B131.0 X36.119
N29   B132.0 X35.964
N30   B133.0 X35.805
N31   B134.0 X35.639
N32   B135.0 X35.479
N33   B136.0 X35.327
N34   B137.0 X35.160
N35   B138.0 X35.099
N36   B139.0 X34.846
N37   B140.0 X34.679
N38   B141.0 X34.519
N39   B142.0 X34.459
N40   B143.0 X34.201
N41   B144.0 X34.042
N42   B145.0 X33.883
N43   B146.0 X33.724
N44   B147.0 X33.563
N45   B148.0 X33.399
N46   B149.0 X33.239
N47   B150.0 X33.079
N48   B153.0 X32.929
N49   B152.0 X32.768
N50   B153.0 X32.607
N51   B154.0 X32.443
N52   B155.0 X32.287
N53   B156.0 X32.119
N54   B157.0 X31.968
N55   B158.0 X31.807
N56   B159.0 X31.646
N57   B160.0 X31.472
N58   B161.0 X31.327
N59   B162.0 X31.181
N60   B163.0 X31.079
N61   B164.0 X31.023
N62   B165.0 X31.045
N63   B166.0 X31.082
N64   B167.0 X31.034
N65   B168.0 X31.083
```

By comparison, the equivalent NC blocks of the spline program (65 linear blocks have been translated into 4 spline blocks):

```
%MPF 2222
N0  G1 F10000 X0.000 Y0.000 Z0.000 B0.000 C0.000
N1  X38.494 B94.000
N5      G6 X38.420 B98.000 I4.001
        K7479172 K-24872128 K13544407
        K138283 K-494686 K-268164648
N12     G6 X38.009 B115.000 I17.011
        K-1092658 K-1255846 K18516670
        K-13440 K-174386 K-267781410
N15     G6 X37.745 B118.000 I3.607
        K1982335983 K-2245320190 K239699980
        K-151548408 K309309875 K-300711934
N64     G6 X31.034 B167.000 I51.515
        K-168507 K3586647 K25742689
        K584696 K-14891629 K-207929854
N65     G1 X31.083 B168.000
```

Note:

The number of the spline block is always the number of the linear block converted last.

4 Working Examples of the Spline Interpolation Method

4.1 Five-axis milling: Backrest of a chair

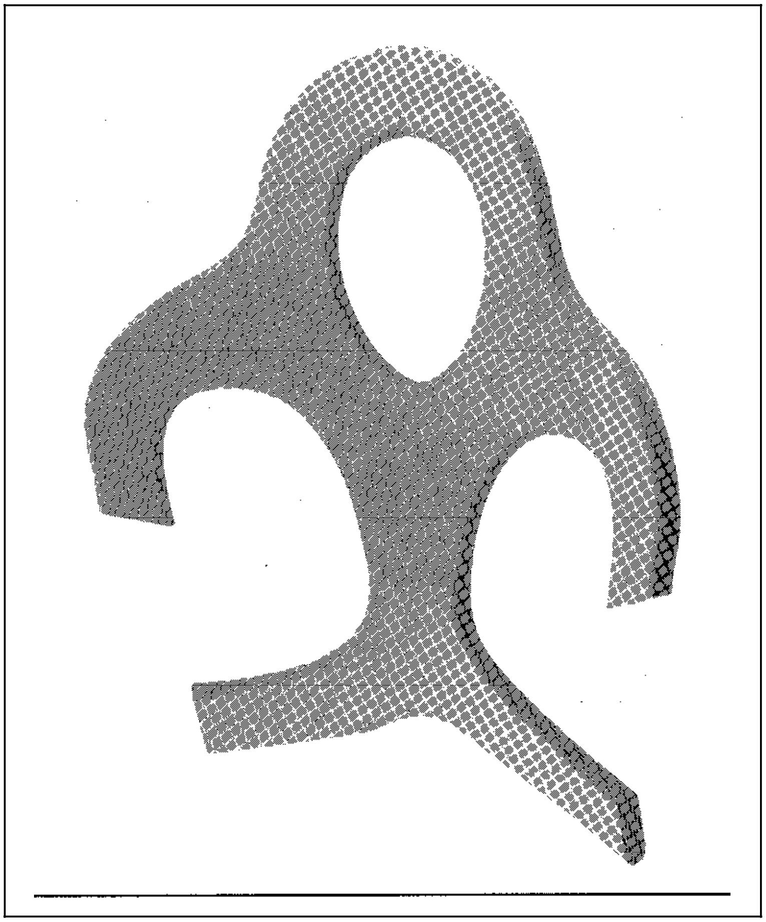

Fig. 4.1 Backrest of a chair, made of wood

Notes on the chosen procedure:

- Recording of contour using play back: 16 spline points and mirroring at the axis of symmetry.
  (Recording a point for 5-axis milling took about 4 minutes. Considering the time required, there is a significant difference between recording only 16 points or more than 100 points.)
- Data transfer NC - PC
- Approximation
  Chosen method: ”Dynamic natural splines” (11)
- Data transfer PC - NC
- Use of SINUMERIK spline interpolator in the numerical control.

4.2 Free form surfaces: Phone receiver

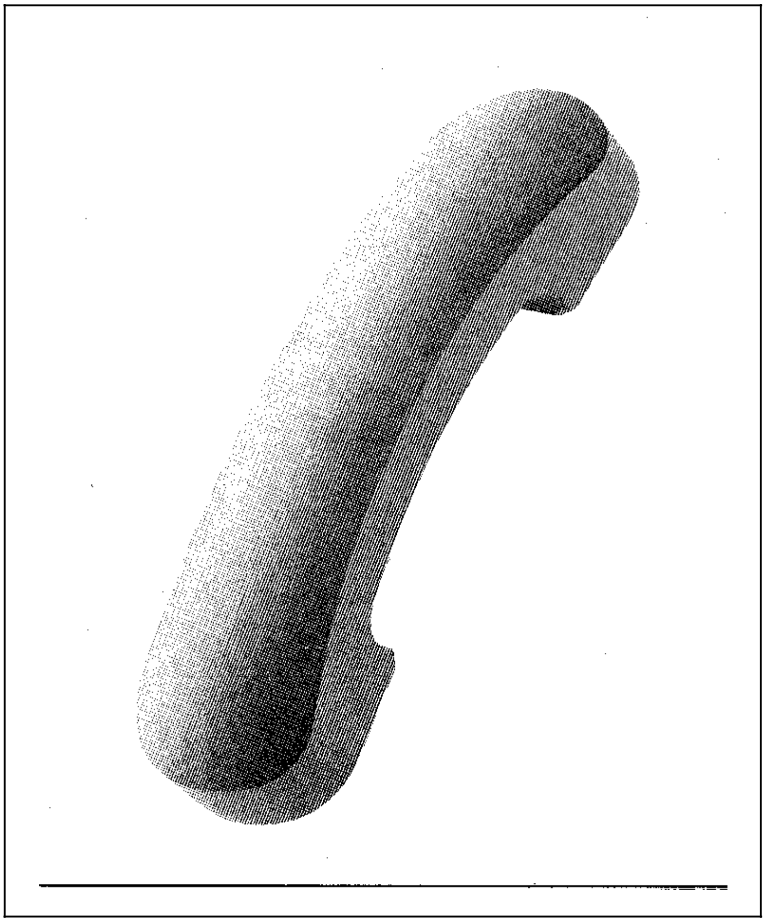

Fig. 4.2 Milled phone receiver

Notes on the chosen procedure:

- Recording of the geometry data of the free form surface at the CAD station and generation of the NC program (**1300** linear blocks) with a postprocessor.
- Chosen roughing method: ″Newton's approximation method″ (1)
  Result: **300** spline blocks
- Chosen finishing method: ″Dynamic natural splines with data reduction″ (12)
  Result: **480** spline blocks

5 Hardware Requirements

The approximation software, i.e. the TRANSLATOR, can be installed on the following computers:

PG 685, PC 16-20, PC 32-05

The TRANSLATOR can be used on other personal computers with MSDOS operating system, but it has not been tested and thus there is no seller's warranty.

Approximation using the TRANSLATOR should only be used in combination with a SINUMERIK control equipped with the proper interpolator (Spline Interpolation option).

Example of complete hardware and software for spline interpolation:

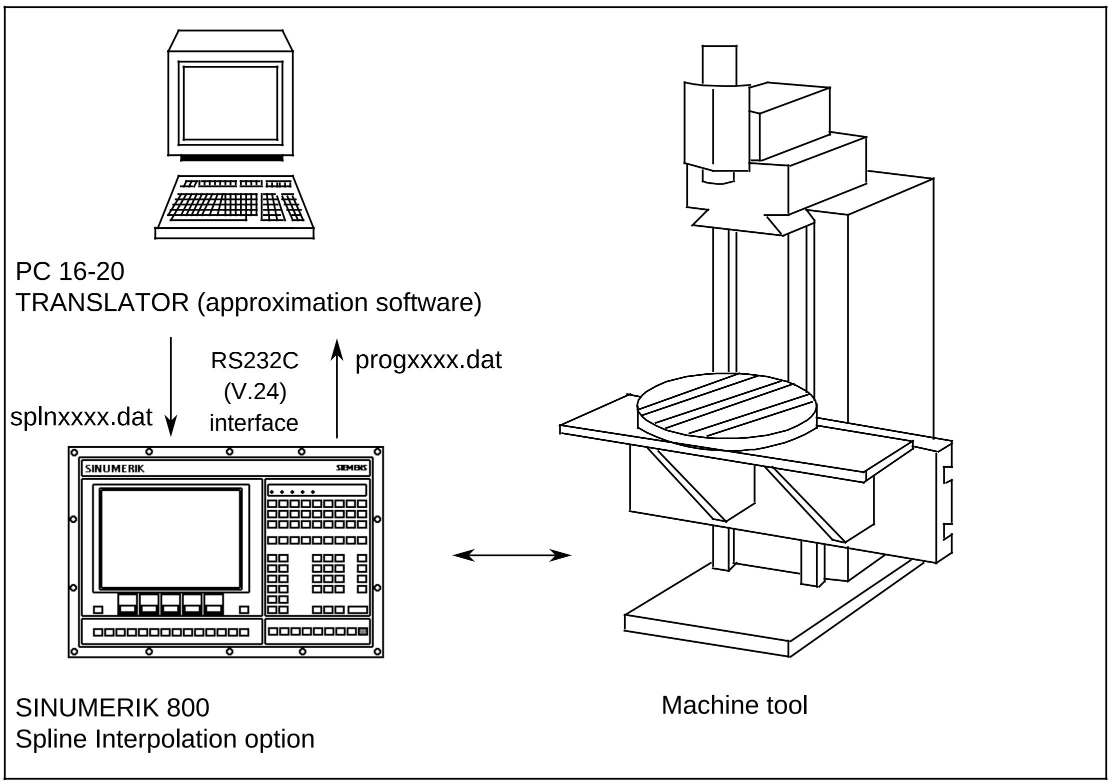

Fig. 5.1 Complete hardware and software for spline interpolation

You will find a description of the required RS232C (V.24) connection cable and more information on how to parameterize the PC/NC interface in the ”Data Transfer TRANS-PCIN/ TRANS PGIN” User's Guide.

6 Information on Installing the TRANSLATOR

The approximation software TRANSLATOR consists of the following files:

TRANSLAT.EXE	Program file
TEXT.FIL	Text file with the texts for the menu and the screen forms
PCFIL.DAT	File containing hardware data
PCIN.EXE	Transfer program for transferring data from PC to NC and vice versa
CONFIG.FIL	Configuration defaults for certain values can be set in this file. These are then displayed automatically in the screen form. More information on entering and modifying these values are given in the file itself.
TRANSIN.BAT	Batch file for installing the TRANSLATOR on a hard disk
TRANSRE.BAT	Batch file for copying the TRANSLATOR back to the original diskette

The TRANSLATOR software is copy protected. The original diskette can be copied onto one hard disk. The TRANSLATOR files can be recopied into various directories. If the TRANSLATOR is to be copied onto a different hard disk, it must be copied back onto the original diskette first and then installed again.
If the TRANSLATOR is to be started from any other directory after installation, the following must be added to the AUTOEXEC.BAT file:

set transdir = ”path to the directory in which TRANSLATOR was installed”

Example:

If the original diskette is in drive A: and if the TRANSLATOR software is to be copied to hard disk C: in the ”translat” directory, the following command must be entered:

a:
transin a: c: \ translat

If the TRANSLATOR software is to be copied from hard disk C: to the original diskette in drive A:, the following command must be entered:

c: \ translat
transre c: a:

If, for instance, the TRANSLATOR was installed in the ”translat” directory, the following must be added in the AUTOEXEC.BAT file:

**set transdir = \ translat **