REIS ROBOTICS

DOCUMENTATION

REIS GMBH & CO MASCHINENFABRIK OBERNBURG

General

Title: : tool calibration

Author:	ESS
Date:	09.04.2005
Control version:	RSV-PCX
Software revision:	17.0
Documentation for level:	as of 3

Date: 15.02.2006

Release: i.A. Elter

Document revisions

Date	Vers.	SW Vers.	Author	Description of changes
09.04.2005	1.0	17.0	Froschauer	Extension by calibration mode 8
14.02.2006	1.1	17.0	Elter	chapter 6.2 revised.

1 TABLE OF CONTENTS

2 General Description

With the automatic tool measurement the dimensions and the orientation of a tool mounted to the robot are to be determined.
With this information the robot control can refer the coordinates of the positions to be controlled to the tool tip (in short TCP from **T**ool **C**enter **P**oint)

As measurement by hand is very time consuming and is especially difficult for orientation and requires additional knowledge on the directions of the three coordinate axes at the robot flange, it should be performed automatically by the system.
Depending on the robot type and the number of its axes the robot has a different number of degrees of freedom. As of software version 10.0 the best possible method for determination of the tool data is derived from this.

Furthermore no additional measuring devices would be required for automatic tool measurement.

3 Target group

Setter

Service personnel

4 Safety instructions

For automatic tool measurement it is necessary to program positions very exactly. This means that the programmer stands in close proximity to the robot.
Therefore it is mandatory to position the key switch at the portable teach pendant to "set" and not to "auto test".

5 Prerequisites: Hardware and Software

Functionality for automatic measurement of a tool is available as of software version 4.0.

For an exact tool measurement it is essential that the robot itself was measured exactly, otherwise there might occur inexact tool data or excess of internal monitoring limits with corresponding error message.

6 Operation

As of RSV-PCX version 12.0 the automated tool measurement has been extended.

It is now possible to determine the tool in two ways:

- manually by programming a calibration program and subsequently calling of the tool calibration (conventional method)

- automatically by starting an automated measuring sequence with the help of appropriate sensors (e.g. a light barrier).

6.1 MANUAL TOOL MEASUREMENT

Depending on the robot type and the number of grades of freedom resulting hereof, there are three possibilities how to determine many components of the tool:

- 6 degrees of freedom => complete determination of X, Y, Z, A, B, C (e.g. RV-kinematics)

- 4 or 5 degrees of freedom => Z component cannot be determined and must be entered subsequently by hand. (e.g. RL-kinematics with fourth axis as rotary axis or RL kinematics with 5 axes)

- 3 degrees of freedom => only the tool frame (orientation A, B, C of the tool) may be determined (e.g. RL-kinematics with 3 axes

Up to version 10.0 it was tried as a matter of principle to determine the tool completely. Especially with kinematics with less than 6 degrees of freedom errors could result.
As of version 10.0 the calibration mode of the control was selected using the machine data IROBOT_TYPE_E.
Now as before it is possible not to have all components determined but only part of these. For this purpose only those positions are programmed that are necessary for the requested calculation (refer to chapter ..).

6.1.1 Measuring program as of version 10.0

To perform the measurement a short program has to be generated first indicating the name of the tool variable (always starting with the letter "T" for "Tool", a segment with position steps for measurement of translational shares (X, Y, Z) starting with "I TRANSLATION" and one segment with 3 position steps for measurement of the rotatory shares starting with "I ROTATION". This program may be a main or a sub-program. The structure is as follows:

```
MPR "Program name"
VAR Name:T1
COPY source, Dest_Var:T1
TOOL T1
C     Determination of the positions for measurement of
the
C     translational tool shares
C     (standard measurement)
C========================================
I TRANSLATION
POSITION 1
POSITION 2
POSITION 3
...
POSITION n            (n <= 10)
C     three further positions for measurement of the
C     rotatory tool shares (on option)
C     (extended measurement)
C========================================
I ROTATION
POSITION n+1
POSITION n+2
POSITION n+3
END
```

In a.m. example the new calculated tool is deposited into tool variable T1.

After the control step "I TRANSLATION" minimum 4 and maximum 10 positions are programmed with a robot with 6 degrees of freedom, between 3 and 10 positions with a robot with less degrees of freedom. If no position was programmed, no translational measurement will be performed (the components X,Y and Z of the tool variable remain undetermined). In case more positions are programmed than the minimum quantity, then the tool calibration designates several results from the

combination with the number of positions required as a minimum and takes the mean. Thus a more precise result may be expected than with the minimum number of positions.
After the control step "I ROTATION" there are either three or no position steps at all. If no position step was programmed, no translational measurement will be performed (the components A, B and C of the tool variable remain undetermined).

6.1.2 Measuring program before version 10.0

For reasons of compatibility the old structure of the measurement program is supported, structure as follows:

```
MPR "Program name"
VAR Name:T1
COPY source:, Dest_Var:T1
TOOL T1
C     Determination of the positions for measurement of
the
C     translational tool shares
C     (standard measurement)
C========================================
POSITION 1
POSITION 2
POSITION 3
POSITION 4
C     further three positions for measurement of the
C     rotatory tool shares (on option)
C     (extended measurement)
C========================================
POSITION 5
POSITION 6
POSITION 7
END
```

Here the I-steps are missing and the number of the positions for translational measurement was fixed to 4. This program structure only supports robots with 6 degrees of freedom. For new generated measurement programs it should no longer be used.

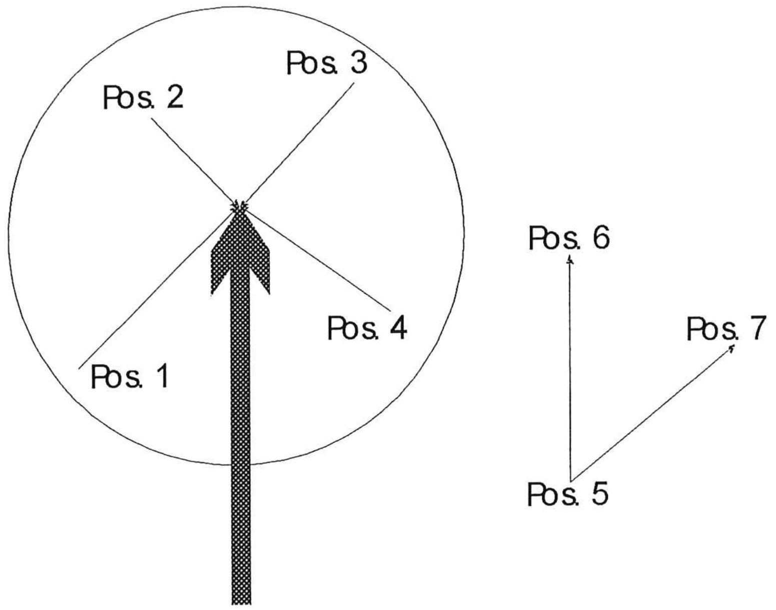
6.1.3 Notes regarding programming of positions

Generating the measurement program, observe the following:
The first n positions for calculation of the translational tool shares have to be programmed such way that the requested tool tip (the later TCP)

always points to the same place in space while the tool flange always is at different positions in space. Thus the tool flange for all n positions is at a surface of a sphere or on a circular plane for robots with less than 6 degrees of freedom) and the TCP is always on their centers.
If the robot has less than 6 degrees of freedom (e.g. RL with 5 axes), it is not always possible to determine all components of the tool.

For maximum accuracy of the measurement it is necessary to select flange positions that are in a distance to each other as far as possible. In case the flange positions are too close to each other, the measurement will be interrupted with a corresponding error message. The minimum distance of the flange positions is adjustable via machine data RTOOLCALFACT. The data is a multiplication factor being multiplied with the calculated spherical radius and resulting in the minimum distance (standard setting of RTOOLCALFACT: 0.5). This factor will be applied unchanged if exactly the minimum number of positions is programmed. With each additional position it is reduced by 1/(n+1), n indicating the number of the additional positions. One additional position will result in the minimum required distance being divided in two, two additional positions will result in being divided in three etc.

The last three positions must have the same orientation. Modification of the orientation will result in an error message and in abort of the measurement. These last three positions indicate the axes directions of the tool coordinate system (in short TCS) and have to be set as follows:
Position n+1 represents the origin of the TCS
the vector between position n+2 and position n+1 the new X-axis
the vector between position n+3 and position n+1 the new Z-axis.
The two calculated vectors are orthogonalized internally starting from the new vector, that means, they will be aligned such way that the Z-vector stands on the X-vector in a 90° angle and the calculated Y-vector also shows a 90° angle towards the other two vectors. Minor inaccuracies during programming of these three positions are of no importance.



Illus. 1: Example with 7 positions for complete tool measurement

6.1.4 Start measurement

For starting the measurement in the FUNCT menu CALIB has to be selected and in the following menu "TOOL" has to be selected. The name of the calibration program generated earlier having been entered with the position steps, the calculation will be done and after the message "calibration terminated" the new tool variable will be provided. Same should be controlled for useful values with INFO VARIABLE "Tool variable".

6.1.5 Important machine data

Name:	Significance:
RTOOLCALFACT	Minimum distance of flange positions available as of version RSV 4.0 Default: 0.5
RTOOL_VEC_DIFF	Max. vector difference of individually calculated tool data of calculation algorithm. This machine data influences

the release of the “internal calculation error 519” or of error S495
Available as from version RSV 5.3
Default: 10.0 [mm]

Remarks:
In the standard calculation a vector difference is built between the four programmed calibration positions and a calculated central point of the sphere. Four vectors are available as result, each describing the tool to be calculated. These four tool vectors vary from each other due to

- programming inaccuracies
- robot measurement inaccuracy
- or wrongly set machine data (observe reference point)

normally in [mm] range.

This **maximum vector difference** can be set using the machine data RTOOL_VEC_DIFF. The calculation algorithm exceeding this barrier, then the ”internal calculation error 519” will result.

ATTENTION:

Increase of the machine data on the one hand prevents the mentioned error message, but **always points out to a wrongly set or badly measured robot.**

6.2 AUTOMATED TOOL MEASUREMENT

The automated tool measurement is applicable since version 12.0. Essentially, it is configured as user program.

By means of suitable sensors (e.g. a light barrier switching very exactly and measuring in the coordinate system of the robot) this program searchs the geometrical dimensions of the tool used. The data determined is made available to the system software via a system variable. The tool variable to be calibrated is generated from this data.

Limitations:

- The automated tool measuring only functions with complete kinematics, i.e. with robots with 6 main axes.
- The Z-direction of the tool to be measured must not lie resp. be laid parallel to the flange Z-direction.

6.2.1 Automatic TCP measurement prior to version 17.0

The user program has to determine the components X, Y and Z of the tool by means of appropriate search strategies. For further treatment later on, this data has to be copied to the system variable
_RAUTOTOOLCAL_TCP[3].
Doing so, the x-component of the tool must be stored in
_RAUTOTOOLCAL_TCP[1], the y-component in
_RAUTOTOOLCAL_TCP[2] and finally the z-component in
_RAUTOTOOLCAL_TCP[3].

It is mandatory that the values of this system variable are available in the flange frame (calling the calibration command with control word 7, see chapter 6.2.3), i.e. these are the values that can be found after the calibration in the translatory part of the tool variable.

For determination of the tool orientation the tool has to be aligned parallel to the Z-direction of the calibrated sensor frame by means of searching for appropriate tool dimensions. This position is given to the control software in the system variable _PAUTOTOOLCAL_POS1.

In addition, the frame number of the sensor frame in the system variable _IAUTOTOOLCAL_FRAME, and the name of the tool variable to be calibrated in _SAUTOTOOLCAL_TOOL are required.

After all the required system variables have been inscribed with correct values, the calibration can be started. For starting the conversion, the control word of the command `CALIBRATION` is set to 7.

Please continue reading at chapter 6.2.3.

Due to the system this variant will not supply the correct tool orientation any way and therefore we recommend to change the tool calibration to the new variant with a system update (see chapter 6.2.2).

6.2.2 Automatic TCP measurement as of version 17.0

As of version 17.0 the calibration regarding the handovers in the system variables behaves different than earlier.

The difference to the previous calibration on the one hand is the delivery of the calibration position in _PAUTOTOOLCAL_POS1. This position variable absolutely must be delivered in the sensor frame and includes a position of the tool being aligned in Z-direction of the sensor frame.

Since the position is absolutely delivered in the sensor frame, the use of the system variable _IAUTOTOOLCAL_FRAME is omitted at the same time. This variable is not evaluated any longer.

The contents of the system variable _RAUTOTOOLCAL_TCP[1 ... 3] no longer absolutely needs be delivered in the flange frame of the robot, but it is also possible to deliver the values in the sensor frame. The advantage is that all the calculations for determination of the TCP may be designed a little clearer.

The system software, however, must be informed about the data frame in _RAUTOTOOLCAL_TCP[ ] now. This happens when starting the calibration.
For starting the conversion from _RAUTOTOOLCAL_TCP[ ] the control word of the command `CALIBRATION` is set to “8”.
In case the conversion must not happen, the control word of the command `CALIBRATION` is set to “7”.

Please continue reading at chapter 6.2.3.

6.2.3 Call of the function

Execution of the calibration is started with the command

```
CALIBRATION Prog_Name:"xxx", control word:7
```

or rather

```
CALIBRATION Prog_Name:"xxx", control word:8
```

is started.

Here, only the command syntax needs the parameter "Prog_Name". The name of any existing program may be entered (e.g. the name of the calibration program using the command).
The parameter "control word" must include the figure 7 or 8, in order to inform the system about the correct calibration mode.

With the control word 7 the translatory part delivered in _RAUTOTOOLCAL_TCP[3] is adopted into the tool variable without changes.

Beforehand, a transformation of the delivered tool vector from sensor frame into flange frame is made by means of the control word 8.

During calibration the following is determined:

- the tool-X-direction of the tool variable to be calibrated is vertical to the plane that is fixed by the sensor frame Z-axis and the flange Z-axis.
- the tool-Z-direction corresponds to the direction of the Z-axis of the sensor frame

The calibration command can be executed either through a macro or through the program sequence.

The necessary system variables represented in a table:

_RAUTOTOOLCAL_TCP[3]	X-, Y-, Z-component of tool calculated by the movement program

_PAUTOTOOLCAL_POS1	the position aligned in the sensor frame by the movement program
_SAUTOTOOLCAL_TOOL	name of the tool variable to be inscribed
_IAUTOTOOLCAL_FRAME	frame number of the sensor frame (used only with calibration command with control word 7)

7 Error Messages/ Debugging

7.1 ERROR MESSAGES

Error No.	Description of fault	Cause	Remedy
S326	Function not implemented	For this robot type no tool calibration is possible	The tool variable has to be described manually.
S495	One or several positions in the segment translation are programmed too imprecisely or the robot is not exactly calibrated.	Deviation of the internally calculated tool vectors to each other exceeds the limit value.	Ensure, that the robot was measured exactly Program positions more precisely
S496	In segment rotation there are not included 3 position steps. XXX steps are programmed.	Wrong number of position steps programmed	Program either no or exactly 3 positions
S497	The number of position steps in segment translation does not correspond to the minimum	Wrong number of position steps programmed	Program at least 4 (robot with 6 degrees of freedom) or 3 positions (robot with less

Error No.	Description of fault	Cause	Remedy
	number. xxx steps are programmed.		degrees of freedom)
S507	Syntax error in the calibration program XXX XXX = 500 XXX = 501 - 507	The following is missing in the calibration program: Tool step Position step (1 – 7)	Insert missing element
S508	Distance of tool flange between pos. X and pos. Y too small	Distance between: Pos. x and y	Re-program the corresponding positions correctly.
S509	Orientation of the positions in the segment rotation is not identical.	Orientation of the positions was changed	Re-program the corresponding positions correctly.
S510	Internal calculation error XXX		

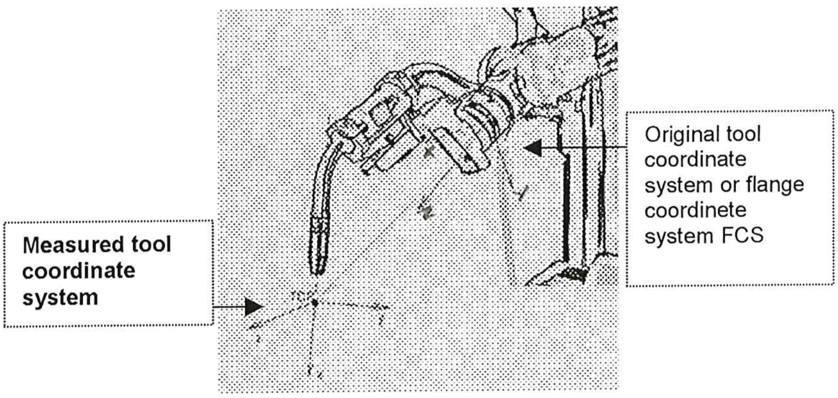
Error No.	Description of fault	Cause	Remedy
	XXX = 508	sphere/circle center cannot be calculated	Program positions 1-4 correctly
	XXX = 518	error with transformation	Position reference tip in a different way
	XXX = 519	error during programming of the calibration positions: one or several of the positions 1 -4 was programmed too inexactly	Ensure that the robot is measured exactly Program positions more exactly
S511	Tool definition not found.	Tool variable was not defined	Define tool variable (VAR "Toolname")

8 Appendix

8.1 THEORETICAL CONSIDERATION

Purpose of the tool measurement is to determine the dimension and the orientation of the tool and to enter these into a tool variable. In order to be able to interpret the importance of the variable contents it will be useful to know the axes of the coordinate system which are the basis of this variable:

The coordinate origin is on the flange plane in the center of the flange. The Z-axis points out of the flange, in the illustration below the X-axis shows horizontally to the rear (parallel to wrist axis) and the Y-axis shows to the bottom in a 90° angle hereof.



Illus. 2: Representation of the tool coordinate systems

To explain this, it is possible to switch over the coordinate system with COORD KART TOOL and to run the directions with X+/X-, Y+/Y-, Z+/Z-.

After successful measurement the new tool variable will be available and can be checked by means of the variable display (keys <INFO>; <F4> (variable); enter the variable name directly up to 9.1, as of 9.2 select new variable with <F1> and then enter name). 6 values will be indicated, the first three will be length indications, the other three will be angles. These indications have to be understood such way that the work point (see TCP in illus. 2)of the tool starting from the flange zero point will be shifted into X, Y and Z direction by the corresponding value (first three values) and afterwards turned by the indicated angle value round X, Y and Z. The values indicate a shifting and a rotation referred to the flange coordinate system (in short FCS).

It may be useful to roughly estimate the lengths and orientations of the tool prior to starting tool measurement and to enter these into the used tool variable. Therefore a short description of the commands for description of the tool variable will follow:

The variable type tool is – as already described - defined as follows in the ROBOTstarV:

1. **X-shifting**
2. **Y-shifting**
3. **Z-shifting**
4. **Rotation around the x-axis of the FCS**
5. **Rotation around the y-axis of the FCS**
6. **rotation around the z-axis of the FCS**

The following structure element names are derived from this for copying by components:

T-Var.**X**
T-Var.**Y**
T-Var.**Z**
T-Var.**RX**
T-Var.**RY**
T-Var.**RZ**

As an example number constants are copied into a Tool variable:

COPY	Source:	15	,	Dest_Var:T-Var.**X**
COPY	Source:	-145	,	Dest_Var:T-Var.**Y**
COPY	Source:	230	,	Dest_Var:T-Var.**Z**
COPY	Source:	-56	,	Dest_Var:T-Var.**RX**
COPY	Source:	75	,	Dest_Var:T-Var.**RY**

COPY Source: -90 , Dest_Var:T-Var.**RZ**

8.2 ROBOT KINEMATICS AND THEIR MEASURING TYPES (MANUAL MEASUREMENT)

Robot kinematics	**Measuring type**
RV kinematics	complete tool determination.
RVL kinematics	complete tool determination.
RH-kinematics (6 axes)	complete tool determination.
RH-kinematics (4 axes)	incomplete tool determination. The Z-component is not determined and has to be added manually later.
RP kinematics	incomplete tool determination. The Z-component is not determined and has to be added manually later.
RL-kinematics (3 axes)	incomplete tool determination. Only the rotation components of the tool can be determined. The translational components have to be added manually later.
RL-kinematics (4 axes)	incomplete tool determination. The Z-component is not determined and has to be