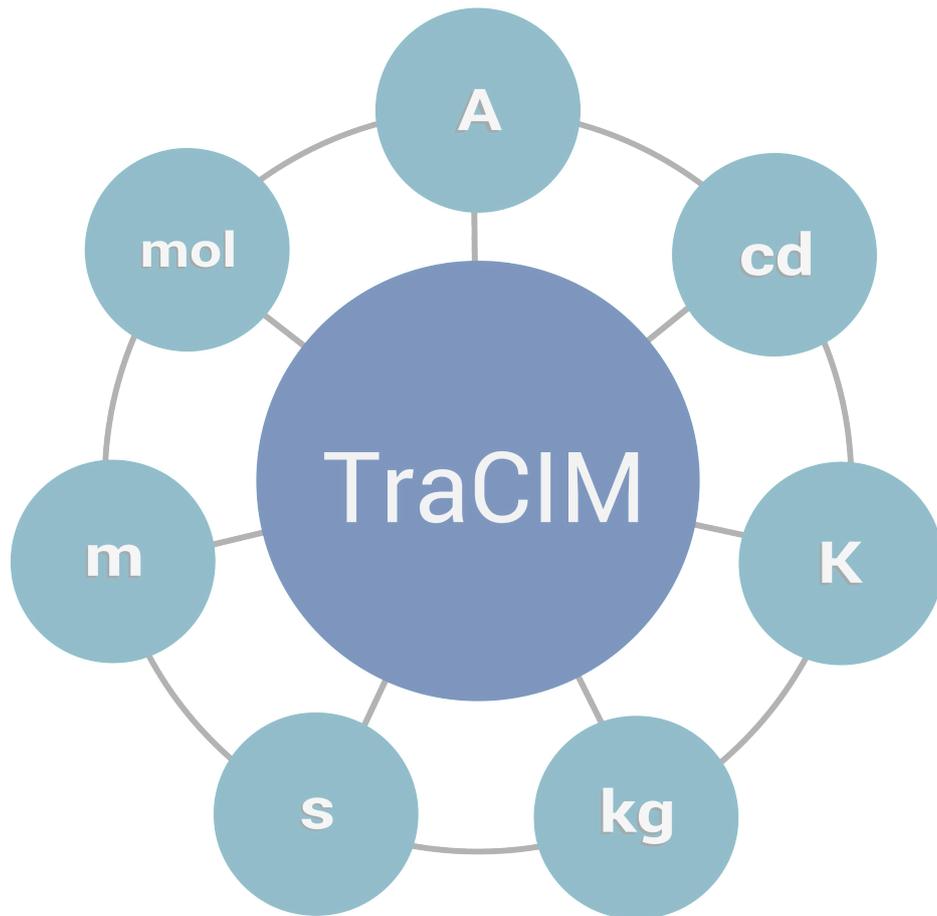


# Traceability for Computationally-Intensive Metrology

## Validation of three-dimensional Screw Thread Algorithm Implementation



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## 1 Introduction

The three-dimensional Screw Thread evaluation test is provided by the PTB TraCIM Online System ([tracim.ptb.de](http://tracim.ptb.de)) and can be ordered by registered customers. To perform a test the customer will get an XML file with data sets containing synthetically generated data in a specified format. Task of the customer is to process this data according to the Computational Aims [1] [3] for this task and send back the results to the TraCIM system. The TraCIM system automatically compares the customer results with its own reference values and sends a report with the test conclusion. Evaluation procedures are described in Section 2.

The data exchange with the TraCIM system is provided by a RESTful web service. All data is exchanged in XML format. For the communication with the TraCIM system, it is recommended to use a client application which also takes care of the (de)serialization of the XML strings. In Section 3.1 support for developing such a client can be found. The XML schemata used for data exchange are described in Section 4.

Tests can be bought in a web shop ([tracim.ptb.de](http://tracim.ptb.de)) by registered customers. A test consists of ten test data sets, each representing the data for an areal-based screw thread measurement according to the method described in [3]. After successful purchase of a test the customer will get an order key that allows him to request test data from the TraCIM system with his client application.

In order to check the functionality of the customer's TraCIM client, a charge free test with public sample data is provided. A registered customer is allowed to request a test with these data sets from the TraCIM system at any time in order to evaluate the correct function of his client-server communication. See Section 3.2 on how to request sample test data sets.

The PTB TraCIM system was developed within the frame of an EURAMET project founded by the European Union (EMRP project NEW06: Traceability for computationally-intensive metrology, [www.ptb.de/emrp/tcim.html](http://www.ptb.de/emrp/tcim.html)) and is under strict quality control of TraCIM e.V. Association.

## 2 Test result evaluation

For the validation, the test results calculated by the customer software are compared to the associated reference results in the TraCIM system data base. For a positive test conclusion all deviations between customer values and reference values must be smaller than the maximum permissible error values (MPE). These MPEs are specified by the customer.

- If the customer specifies MPEs equal to zero, the default values for all quality characteristics are:

Characteristic variable	Unit	MPE
Size	$\mu\text{m}$	$10^{-3}$
Angle	$\mu\text{rad}$	$10^{-2}$
Taper of pitch cone	1	$10^{-8}$

- Admissible non-zero values specified by the customer must satisfy:

Minimum	MPE	Maximum
$10^{-4} \mu\text{m}$	$\leq \text{Size} \leq$	$10^{-2} \mu\text{m}$
$10^{-3} \mu\text{rad}$	$\leq \text{Angle} \leq$	$10^{-1} \mu\text{rad}$
$10^{-9}$	$\leq \text{Taper of pitch cone} \leq$	$10^{-7}$

Other values for the MPE are not accepted and cause an error message.

### 3 Client-server communication

The test procedure is highly automated using internet based data exchange by client-server communication via a REST interface. Using a REST client application the user is able to obtain test data sets and send back the calculated results.

The data exchanged between client and server is encapsulated within XML. A proper specification of the applied XML data schemata is given in Section 4. The messages send between the client application and the TraCIM system server are treated as plain character strings.

#### 3.1 Development of a client application

**Configuration of the HTTPS connection:** The communication between the TraCIM server and the client application is established via HTTPS (Hypertext Transfer Protocol Secure = encrypted HTTP) connection that allows to send and receive content in the form of character strings containing messages in XML format. Each HTTPS connection is created from a specific URL (Uniform Resource Locator). The following configurations are necessary:

- Set the request method “POST” (request comprising input and output)
- Set connection property “Content-Type” to “application/xml”
- Set connection property “Accept” to “application/xml”

Packages for creation and configuration of an HTTPS connection are available for different programming languages, e.g.:

- Java: java.net API
- C/C++: Microsoft C++ REST SDK or similar
- C#: .NET Framework (System.Net.Http)

**POST request for obtaining test data sets:** The URL of an HTTPS connection for the POST request to obtain test data sets is

```
https://tracim.ptb.de/tracim/api/order/<THREAD3D_ORDER_KEY>/test (3.1)
```

where <THREAD3D\_ORDER\_KEY> has to be replaced by the order key for the test purchased at the TraCIM web shop. When the TraCIM system receives the client message it will create a unique process key associated with this test process. Test data and process key are then returned to the client. In case of an incorrect order key the TraCIM server will send an error message. Details about the format of the delivered test data are described in Section 4.2. Error messages are addressed in Section 4.5.

**Example 3.1** *A simple way to communicate with the TraCIM server is using the command line tool cURL (<https://curl.haxx.se>). To get test data for the order key <THREAD3D\_ORDER\_KEY> and save the response to the file `testdata.xml` one can use the following command:*

```
curl -X POST https://tracim.ptb.de/tracim/api/order/<THREAD3D_ORDER_KEY>/test  
-o testdata.xml
```

*(In case one gets an error about unknown CA certificates or similar, one may need to download the certificate bundle `cacert.pem` from <https://curl.haxx.se/docs/caextract.html> and use additionally the option `--cacert cacert.pem`.)*

**POST request for sending test results and obtaining the certificate:** When the customer has processed the test data sets according to the Computational Aims, he has to prepare the XML content with his results as described in Section 4.3. The URL of the HTTPS connection for a POST request in order to send the prepared XML string is

`https://www.tracim.ptb.de/tracim/api/test/<PROCESS_KEY>` (3.2)

where `<PROCESS_KEY>` has to be replaced by the individual process key that was returned by the TraCIM system together with the test data. The TraCIM system will then evaluate the content and generate a test report. It states whether the test is passed, or otherwise contains a list of the values which didn't pass the test for all elements T01-T10. (In case of a free sample test the report is not signed and does not contain the PTB seal.) The report is encoded in XML and sent to the customer as return message to the POST request (3.2). See Section 4.4 for a description of the XML content returned by the TraCIM system. As soon as the test report is sent to the customer, the associated process key cannot be used again, irrespective of whether the test was passed or not.

**Example 3.2** *To send the file `results.xml` with the calculated results for the process with key `<PROCESS_KEY>` to the TraCIM server and save the server response to the file `validation.xml` with the command line tool `cURL` use*

```
curl -d @calculated_result.xml -H "Content-Type: application/xml"
      -X POST https://tracim.ptb.de/tracim/api/test/<PROCESS_KEY>
      -o validation.xml
```

*(As in Example 3.1 one may also need to use the option `--cacert cacert.pem`.)*

For the case of an improper process key or an malformed or incomplete XML content the TraCIM system returns an error message, see Section 4.5 for a description. In this case, the associated process key is still valid, so the customer can fix the problems in the XML content and send the results again.

**Remark 3.3** *After receiving an order key a customer has a total of 200 days for performing the Three-Dimensional Screw Thread test. The TraCIM system will occasionally send warning messages to the customers e-mail address stating the remaining time for the order. A final information message is sent three days before the order expires.*

## 3.2 Public sample data for client testing

Any registered customer can order sample test data free of charge with unlimited request amount for backtracking errors within the client application that could compromise a commercial test. In comparison to a test with commercial test data the certificate returned by the server is not countersigned by PTB as legally valid certificate. Sample order keys are available in the webshop (`tracim.ptb.de`) for registered customers.

# 4 XML message content

## 4.1 TraCIM XML schemata

The XML schemata which specify the format of the XML files for the data exchange with the TraCIM system can be obtained from the following URLs:

- General TraCIM report schema  
<https://tracim.ptb.de/tracim/api/schema/tracim.xsd>
- 3D screw thread evaluation test data schema  
[https://tracim.ptb.de/tracim/api/schema/PTB\\_MATH\\_THREAD3D\\_v1\\_test.xsd](https://tracim.ptb.de/tracim/api/schema/PTB_MATH_THREAD3D_v1_test.xsd)
- 3D screw thread evaluation result data schema  
[https://tracim.ptb.de/tracim/api/schema/PTB\\_MATH\\_THREAD3D\\_v1\\_result.xsd](https://tracim.ptb.de/tracim/api/schema/PTB_MATH_THREAD3D_v1_result.xsd)

All messages delivered by the TraCIM server have the root element `tracim` of type `tracimMessage` defined in the general TraCIM report schema. These messages may contain order or process information, test data sets according to the 3D screw thread evaluation test data schema, test conclusions, or error messages.

The only XML messages send by the customer are the test results according to the 3D screw thread result evaluation data schema with root element `thread3dResultPackage`.

For the reader's convenience pieces of these schemata are included in Section 4.2-4.5. It is recommended to make use of this schemata during client development, i.e. to automatically build Java, C++ or C# classes.

## 4.2 Test data

Test data returned by the TraCIM system are composed of the three major elements order identification, process identification and test data sets. The order element contains the order key, the date of the creation of the order and the date for the expiration of the order.

The process element contains the process key associated with the test data request. Finally, the test element contains the test data for the 3D screw thread evaluation test, consisting of ten test data sets with the IDs T01-T10.

For each test data set a data block `nominal_values` is provided, that consists of nominal values

- `type`: type of screw thread, external `plug` [2, (3.2.6)] or internal `ring` [2, (3.2.6)] in mm
- `nominal_diameter`: nominal screw thread diameter [2, (5.1)] in mm
- `lead`: lead of the helix at the pitch diameter [2, (6.5)] in mm
- `pitch_diameter`: pitch diameter of the screw thread [2, (5.9)] in mm
- `flank_angle_1`: flank angle of the lower flank 1 in ° [2, (3.2.4), Figure 2, (4.17)], the sign is defined as in [3]
- `flank_angle_2`: flank angle of the upper flank 2 in ° [2, (3.2.4), Figure 2, (4.17)], the sign is defined as in [3]
- `taper_of_pitch_cone`: taper of the thread, which is the dimensionless ratio of the difference between the diameters of two sections to the distance between these in sections [2, (10.11)]

Below is an excerpt of an test data XML string delivered by the TraCIM system for the POST request (3.1):

```

1 <?xml version="1.0" encoding="UTF-8" standalone="true"?>
2 <tracim:tracim xmlns:tracim="http://tracim.ptb.de/tracim"
3     xmlns:thread3d="http://tracim.ptb.de/thread3d/test"
4     xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
5   <tracim:order>
6     <tracim:key>[ORDER_KEY]</tracim:key>
7     <tracim:creationDate>[...]</tracim:creationDate>
8     <tracim:expirationDate>[...]</tracim:expirationDate>
9   </tracim:order>
10  <tracim:process>
11    <tracim:key>[PROCESS_KEY]</tracim:key>
12  </tracim:process>
13  <tracim:test xsi:type="thread3d:thread3DTestPackage">
14    <thread3d:thread3DTestData>
15      <thread3d:basicID>T01</thread3d:basicID>
16      <thread3d:nominal_values>
17        <thread3d:type>PLUG</thread3d:type>
18        <thread3d:nominal_diameter>56.0</thread3d:nominal_diameter>
19        <thread3d:lead>5.5</thread3d:lead>
20        <thread3d:pitch_diameter>52.428</thread3d:pitch_diameter>
21        <thread3d:flank_angle_1>-30.0</thread3d:flank_angle_1>
22        <thread3d:flank_angle_2>30.0</thread3d:flank_angle_2>
23        <thread3d:taper_of_pitch_cone>0.0</thread3d:taper_of_pitch_cone>
24      </thread3d:nominal_values>
25      <thread3d:inspection_values>
26        <thread3d:stylus_diameter>8.000041209217605</thread3d:stylus_diameter>
27        <thread3d:intersection_point>-41.85</thread3d:intersection_point>
28        <thread3d:reference_plane>-30.85</thread3d:reference_plane>
29        <thread3d:thread_pointset flankNumber="1" trackNumber="1">
30          <thread3d:p3D_set>
31            <thread3d:x>27.435132440695956</thread3d:x>
32            <thread3d:y>-0.11916030984316209</thread3d:y>
33            <thread3d:z>-39.31323537625634</thread3d:z>
34          </thread3d:p3D_set>
35          [...]
36        </thread3d:thread_pointset>
37        <thread3d:thread_pointset flankNumber="1" trackNumber="2">
38          <thread3d:p3D_set>
39            <thread3d:x>28.213180193499376</thread3d:x>
40            <thread3d:y>-0.11562679408511682</thread3d:y>
41            <thread3d:z>-39.76232335409691</thread3d:z>
42          </thread3d:p3D_set>
43          [...]
44        </thread3d:thread_pointset>
45      </thread3d:inspection_values>
46    </thread3d:thread3DTestData>
47    <thread3d:thread3DTestData>
48      <thread3d:basicID>T02</thread3d:basicID>
49      [...]
50    </thread3d:thread3DTestPackage>
51  </tracim:test>
52 </tracim:tracim>

```

The process key [PROCESS\_KEY] is created by the TraCIM system when the test data is delivered. This key has to be used by the customer when sending the test results as described in the next section.

### 4.3 Test results

The calculated results of the software under test must be send to the TraCIM system as XML string compliant with the XML schema for the result data (see 4.1, result data schema). The client has to specify the following information:

- [PROCESS\_KEY]: process key received with the test data (section 4.2)
- [SOFTWARE\_VENDOR]: software vendor (can be different from customer name)
- [SOFTWARE\_NAME]: name of software under test
- [SOFTWARE\_VERSION]: version of software under test
- [SOFTWARE\_REVISION]: revision of software under test (optional)
- [MPE\_Length]: MPE in  $\mu\text{m}$  (set the MPE to 0.0 to use the default values)
- [MPE\_Angle]: MPE in  $\mu\text{rad}$  (set the MPE to 0.0 to use the default values)
- [MPE\_Dimless]: Dimensionless MPE (set the MPE to 0.0 to use the default values)

This information is followed by elements that contain the results of the software under test for the basic IDs T01-T10:

- lead\_1: lead of flank 1 (For plugs, flank 1 corresponds to the lower flank. For rings, flank 1 corresponds to the upper flank.)
- flank\_angle\_1: flank angle of flank 1
- lead\_2: lead of flank 2 (For plugs, flank 2 corresponds to the upper flank. For rings, flank 2 corresponds to the lower flank.)
- flank\_angle\_2: flank angle of flank 2
- taper\_of\_pitch\_cone: taper of pitch cone
- pitch\_diameter: pitch diameter
- lead\_of\_helix: lead of helix
- cumulative\_lead\_deviation: cumulative lead deviation

Below is an excerpt of the result XML string which has to be send back to the TraCIM server using the POST request (3.2).

```
1 <?xml version="1.0" encoding="UTF-8" standalone="true"?>
2 <thread3d:thread3DResultPackage xmlns:tracim="http://tracim.ptb.de/tracim"
3   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
4   xmlns:thread3d="http://tracim.ptb.de/thread3d/result">
5   <thread3d:processKey>[PROCESS_KEY]</thread3d:processKey>
6   <thread3d:softwareVendor>[SOFTWARE_VENDOR]</thread3d:softwareVendor>
7   <thread3d:softwareName>[SOFTWARE_NAME]</thread3d:softwareName>
8   <thread3d:softwareVersion>[SOFTWARE_VERSION]</thread3d:softwareVersion>
```

```

9 <thread3d:softwareRev>[SOFTWARE_REVISION]</thread3d:softwareRev>
10 <thread3d:mpe_length>[MPE_Length]</thread3d:mpe_length>
11 <thread3d:mpe_angle>[MPE_Angle]</thread3d:mpe_angle>
12 <thread3d:mpe_taper_of_pitch_cone>[MPE_Dimless]</thread3d:mpe_taper_of_pitch_cone>
13 <thread3d:thread3DResultData>
14   <thread3d:basicID>T01</thread3d:basicID>
15   <thread3d:lead_1>5.4999750462616905</thread3d:lead_1>
16   <thread3d:flank_angle_1>-30.000093633430762</thread3d:flank_angle_1>
17   <thread3d:lead_2>5.5000068005311578</thread3d:lead_2>
18   <thread3d:flank_angle_2>29.999995538459608</thread3d:flank_angle_2>
19   <thread3d:taper_of_pitch_cone>-9.999999998880146E-06</thread3d:taper_of_pitch_cone>
20   <thread3d:pitch_diameter>52.42791942635624</thread3d:pitch_diameter>
21   <thread3d:lead_of_helix>5.4999909234278128</thread3d:lead_of_helix>
22   <thread3d:cumulative_lead_deviation>2.2622890701147944E-05
23     </thread3d:cumulative_lead_deviation>
24 </thread3d:thread3DResultData>
25 <thread3d:thread3DResultData>
26   <thread3d:basicID>T02</thread3d:basicID>
27   [...]
28 </thread3d:thread3DResultData>
29 </thread3d:thread3DResultPackage>

```

#### 4.4 Test report message

After evaluation of the test results the TraCIM system returns the validation conclusion as XML string according to the general TraCIM XML schema. It comprises the three elements:

- **passed:** true, if the software passed the test successfully, else false
- **report:** character string with short report on the test evaluation
- **reportPDF:** character string with the test report PDF (Base64-encoded)

In order to create the test report PDF document as PDF file, the Base64-encoded character string contained in the **reportPDF** tag has to be decoded and written to a new file with the proper **.pdf** file name extension. Below is an excerpt of an XML string with the test conclusion:

```

1 <?xml version="1.0" encoding="UTF-8" standalone="true"?>
2 <tracim:tracim xmlns:tracim="http://tracim.ptb.de/tracim"
3   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
4   <tracim:validation>
5     <tracim:passed>true</tracim:passed>
6     <tracim:report>Congratulations! The test has passed.</tracim:report>
7     <tracim:reportPDF>JVBERi0xLjQKJWlsZX[...]</tracim:reportPDF>
8   </tracim:validation>
9 </tracim:tracim>

```

#### 4.5 TraCIM error message

The following XML code is sent by the server in case of errors, where [error code] and [error description] are replaced with values for the particular error.

```
1 <?xml version="1.0" encoding="UTF-8" standalone="true"?>
2 <tracim:tracim xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
3   xmlns:tracim="http://tracim.ptb.de/tracim">
4   <tracim:error>
5     <tracim:code>[error code]</tracim:code>
6     <tracim:description>[error description]</tracim:description>
7   </tracim:error>
8 </tracim:tracim>
```

In case an error message is received, the error description may contain useful hints what caused the error.

## 5 How to get support

- technical support for client software: `support.tracim@ptb.de`
- support regarding computational aims: `info.tracim@ptb.de`
- Provider support (contact, fees, etc.): `info.tracim@ptb.de`

## References

- [1] Computational Aims: Validation of three-dimensional Screw Thread Algorithm Implementation
- [2] Technical Committee ISO/TC 1 Screw threads, ISO 5408:2009(E/F), International Standard: Screw threads — Vocabulary, Second edition, 2009-06-15
- [3] S. Schädel, A. Wedmann and M. Stein. Advanced screw thread metrology using an areal measuring strategy and a holistic evaluation method. *Measurement Science and Technology*, 2019, 10.1088/1361-6501/ab1501.
- [4] S. Schädel, A. Przyklenk, M. Stein, K. Kniel and E. Manske. Ganzheitliche Kalibrierung von Gewinden auf Basis eines dreidimensionalen Ansatzes. *tm - Technisches Messen*, 2020, 10.1515/teme-2020-003.

# Computational Aims

## Validation of three-dimensional Screw Thread Algorithm Implementation

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# 1 Language

English (en)

# 2 Title

Validation of three-dimensional Screw Thread Algorithm Implementation

# 3 Keywords

- 3D Screw thread measurement
- Plug and Ring
- Screw thread determinants
- Lead
- Flank angle
- Taper of pitch cone
- Lead of helix
- Cumulative lead deviation

# 4 Mathematical area

Non-linear least squares.

# 5 Dependencies

The geometrically ideal form element of a screw thread is parameterized as presented in [2] and consists of two standard screw surfaces  $\mathbf{S}_j$  with  $j = 1, 2$

$$\mathbf{S}_j(\mathbf{u}_j, \mathbf{v}_j, p_{j1}, p_{j2}) = \begin{pmatrix} \mathbf{x}_j \\ \mathbf{y}_j \\ \mathbf{z}_j \end{pmatrix} = \begin{pmatrix} \mathbf{u}_j \cdot \cos(\mathbf{v}_j) \\ \mathbf{u}_j \cdot \sin(\mathbf{v}_j) \\ \mathbf{v}_j \cdot p_{j1} + \mathbf{u}_j \cdot p_{j2} \end{pmatrix}, \quad (5.1)$$

where  $\mathbf{S}_j$ ,  $\mathbf{u}_j$ ,  $\mathbf{v}_j$ ,  $\mathbf{x}_j$ ,  $\mathbf{y}_j$  and  $\mathbf{z}_j$  are vectors of dimension  $N$ , that is the number of inspection values.  $\mathbf{S}_j$  is expressed in Cartesian coordinates and parameterized in cylindrical coordinates with radii  $u_j$  and polar angles  $v_j$ , where  $p_{j1}$  and  $p_{j2}$  denote geometry parameters from which the lead of single flanks

$$\text{lead}_j = 2\pi \cdot p_{j1} \quad (5.2)$$

and the flank angles

$$\text{flankAngle}_j = \arctan(p_{12}) \quad (5.3)$$

can be derived. All screw thread determinants are based on equations (5.1)-(5.3) and a translational degree of freedom  $t_{Zj}$  that corresponds to intersections along the z-axis of the screw thread. Then the pitch diameter is obtained by

$$\text{pitchDiameter} = 2 \cdot \left( \frac{p_{11} - p_{21}}{p_{11} \cdot p_{22} - p_{12} \cdot p_{21}} \cdot z - \frac{p_{11} \cdot t_{Z2} - p_{21} \cdot (t_{Z1} + \pi \cdot |p_{11}|)}{p_{11} \cdot p_{22} - p_{12} \cdot p_{21}} \right). \quad (5.4)$$

## 6 Input parameters: Nominal input parameters

### 6.1 Nominal input parameter 1

**Symbol:**  $\text{type} = (-1, 1)$   
**Description:** Screw thread type  
**Type:**  $\mathbb{Z}$   
**Shape:** scalar  
**Constrains:** either  $\text{RING} = -1$  or  $\text{PLUG} = 1$

### 6.2 Nominal input parameter 2

**Symbol:**  $D$  (RING) or  $d$  (PLUG)  
**Description:** nominal diameter according to DIN 2244:2002-05 (3.3.1)  
**Type:**  $\mathbb{R}^*$   
**Shape:** scalar  
**Constrains:**  $D > 0, d > 0$

### 6.3 Nominal input parameter 3

**Symbol:**  $Ph$   
**Description:** lead of the helix according to DIN 2244:2002-05 (3.1.3)  
**Type:**  $\mathbb{R}^+$   
**Shape:** scalar  
**Constrains:**  $Ph > 0$

### 6.4 Nominal input parameter 4

**Symbol:**  $D_2$  (RING) or  $d_2$  (PLUG)  
**Description:** pitch diameter according to DIN 2244:2002-05 (3.3.10) and [2], table 1, equation (9)  
**Type:**  $\mathbb{R}^+$   
**Shape:** scalar  
**Constrains:**  $D_2 > 0, d_2 > 0$

### 6.5 Nominal input parameter 5

**Symbol:**  $\beta_1$   
**Description:** flank angle according to ISO 5408:2009 (3.2.4) and [2], table 1, equation (4)  
**Type:**  $\mathbb{R}^-$   
**Shape:** scalar  
**Constrains:**  $\beta_1 < 0$

### 6.6 Nominal input parameter 6

**Symbol:**  $\beta_2$   
**Description:** flank angle according to ISO 5408:2009 (3.2.4) and [2], table 1, equation (5)  
**Type:**  $\mathbb{R}^+$   
**Shape:** scalar  
**Constrains:**  $\beta_2 > 0$

## 7 Input parameters: Inspection values

### 7.1 Inspection value 1

**Symbol:**  $d_s$   
**Description:** stylus diameter  
**Type:**  $\mathbb{R}^+$   
**Shape:** scalar  
**Constrains:**  $d_s > 0$

### 7.2 Inspection value 2

**Symbol:**  $z_C$   
**Description:** first intersection point of screw surface  $\mathbf{S}_1$  and  $\mathbf{S}_2$  (equation (5.1)) at the smallest z-coordinate according to [2], figure 2  
**Type:**  $\mathbb{R}^-$   
**Shape:** scalar  
**Constrains:**  $z_C < 0$

### 7.3 Inspection value 3

**Symbol:**  $z_B$   
**Description:** reference plane according to [2], figure 2  
**Type:**  $\mathbb{R}$   
**Shape:** scalar  
**Constrains:** none

### 7.4 Inspection value 4

**Symbol:**  $j = (1, 2)$   
**Description:** flank number according to [2], figure 2  
**Type:**  $\mathbb{N}$   
**Shape:** scalar  
**Constrains:** none

### 7.5 Inspection value 5

**Symbol:**  $(\mathbf{x}, \mathbf{y}, \mathbf{z})$   
**Description:** 3D-point set describes the ball center points, which must undergo a probe radius correction by half of the given probe diameter  $d_s$   
**Type:**  $\mathbb{R}$   
**Shape:** vector of dimension  $N$   
**Constrains:** none

## 8 Output parameters

### 8.1 Output parameter 1

**Symbol:**  $P_1$   
**Description:** single lead of flank 1  
**Type:**  $\mathbb{R}^+$   
**Shape:** scalar  
**Constrains:**  $P_1 > 0$

### 8.2 Output parameter 2

**Symbol:**  $\beta_1$   
**Description:** flank angle of flank 1  
**Type:**  $\mathbb{R}^-$   
**Shape:** scalar  
**Constrains:**  $\beta_1 < 0$

### 8.3 Output parameter 3

**Symbol:**  $P_2$   
**Description:** single lead of flank 2  
**Type:**  $\mathbb{R}^+$   
**Shape:** scalar  
**Constrains:**  $P_2 > 0$

### 8.4 Output parameter 4

**Symbol:**  $\beta_2$   
**Description:** flank angle of flank 2  
**Type:**  $\mathbb{R}^+$   
**Shape:** scalar  
**Constrains:**  $\beta_2 > 0$

### 8.5 Output parameter 5

**Symbol:**  $C$   
**Description:** taper of pitch cone  
**Type:**  $\mathbb{R}$   
**Shape:** scalar  
**Constrains:** none

### 8.6 Output parameter 6

**Symbol:**  $D_2(z_B), d_2(z_B)$   
**Description:** pitch diameter in reference plane  
**Type:**  $\mathbb{R}^+$   
**Shape:** scalar  
**Constrains:**  $D_2(z_B) > 0, d_2(z_B) > 0$

## 8.7 Output parameter 7

**Symbol:**  $Ph$   
**Description:** lead of helix  
**Type:**  $\mathbb{R}_+$   
**Shape:** scalar  
**Constrains:**  $P > 0$

## 8.8 Output parameter 8

**Symbol:**  $\Delta Ph$   
**Description:** Total cumulative lead deviation according to DIN 2244:2002-05 (3.6.11), but within the entire specified length defined by the input 3D-point set  $(\mathbf{x}, \mathbf{y}, \mathbf{z})$   
**Type:**  $\mathbb{R}_+$   
**Shape:** scalar  
**Constrains:**  $\Delta Ph > 0$

# 9 Mathematical model

## 9.1 Form element

The form element to be fitted by the non-linear least squares method into the 3D-point set  $(\mathbf{x}, \mathbf{y}, \mathbf{z})$  is defined in equation (5.1).

## 9.2 Determination of screw thread determinants

The output parameters 1 to 7 are given by the equations summarized in table 1:

Table 1: Output parameters and equations for determination.

output parameter	flank 1	flank 2
lead of single flank	$P_1 = 2 \cdot \pi \cdot p_{11}$	$P_2 = 2 \cdot \pi \cdot p_{21}$
flank angle	$\beta_1 = \arctan(p_{12})$	$\beta_2 = \arctan(p_{22})$
lead of the helix	$Ph = 2 \cdot \pi \cdot \frac{p_{11} \cdot p_{22} - p_{21} \cdot p_{12}}{p_{22} - p_{12}}$	
taper of pitch cone	$C = 2 \cdot \frac{p_{11} - p_{21}}{p_{11} \cdot p_{22} - p_{21} \cdot p_{12}}$	
pitch diameter	equation (5.4)	

## 9.3 Total cumulative lead deviation

Output parameter 8 is determined following DIN 2244:2002-05 (3.6.11). The deviation describes the local lead depending on the z-coordinate as defined in [3] for instance, which is not the least-squares solution.

## 10 Signature

$[P_1, \beta_1, P_2, \beta_2, Ph, C, D_2; d_2, \Delta Ph] = \text{thread3D}(\text{type}, D_2; d_2, Ph, \beta_1, \beta_2, d_s, z_B, z_C, (\mathbf{x}, \mathbf{y}, \mathbf{z}))$

## 11 References

### References

- [1] Technical Committee ISO/TC 1 Screw threads, ISO 5408:2009(E/F), International Standard: Screw threads — Vocabulary, Second edition, 2009-06-15
- [2] S. Schädel, A. Wedmann and M. Stein. Advanced screw thread metrology using an areal measuring strategy and a holistic evaluation method. Measurement Science and Technology, 2019, [10.1088/1361-6501/ab1501](https://doi.org/10.1088/1361-6501/ab1501).
- [3] S. Schädel, A. Przyklenk, M. Stein, K. Kniel and E. Manske. Ganzheitliche Kalibrierung von Gewinden auf Basis eines dreidimensionalen Ansatzes. tm - Technisches Messen, 2020, [10.1515/teme-2020-003](https://doi.org/10.1515/teme-2020-003).

## 12 History

- i.*) Created on 2021-09-13 by Anita Przyklenk (PTB, Germany)
- ii.*) Reviewed on 2021-09-14 by Frank Keller (PTB, Germany)
- iii.*) Updated on 2021-09-28 by Anita Przyklenk (PTB, Germany)