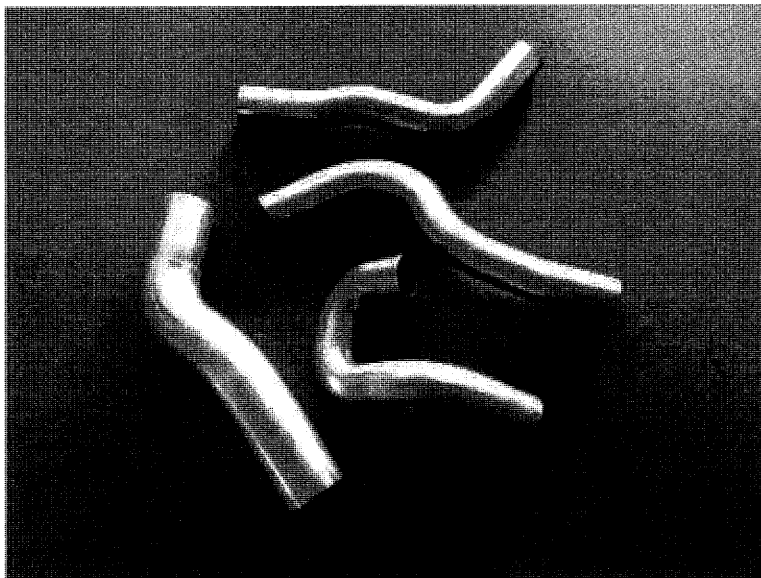


BENDING & GEOMETRY

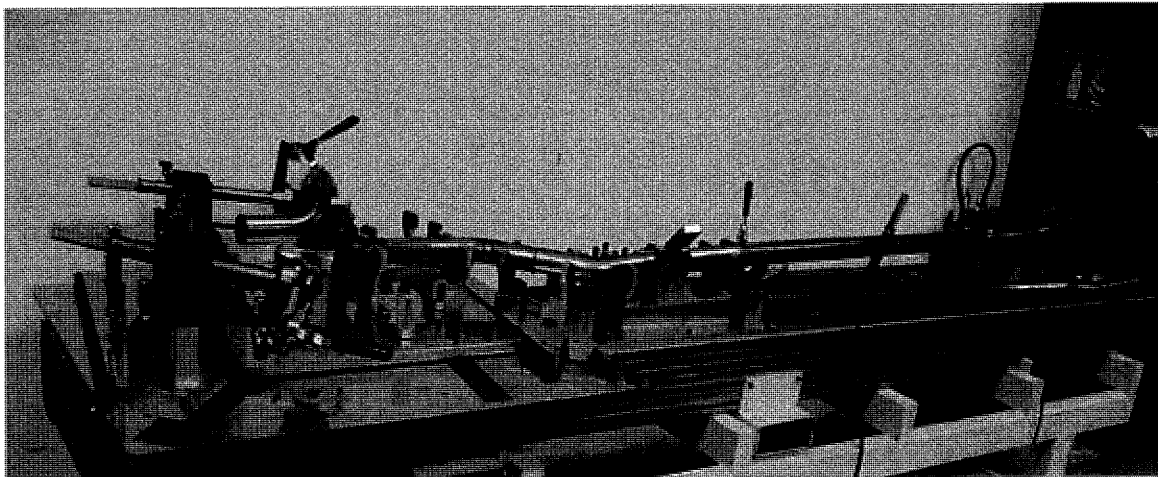
01/2007 Edition



CML INTERNATIONAL

ALL BENDERS

BENDING GEOMETRY 01/2007 Edition



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ALL BENDERS

SUMMARY:

I - SUBJECT

II – FIELD OF APPLICATION

III – INSTRUCTIONS

I – SUBJECT.

The objective of this manual is to provide all information on the geometric aspect of tube bending.

II – FIELD OF APPLICATION.

This manual applies to all machine benders.

III – INSTRUCTIONS.

III – 1 Definitions

Area of plastic deformation:

This is an area in which the material is deformed permanently. The material maintains the form that it has been given.

Area of elastic deformation:

This is an area in which the material is deformed temporarily. The material returns to its initial shape.

Geometry :

The geometry of a piece is its position in space compared with an original system. Regulation of geometry is the production of pieces in accordance with its localisation within a given tolerance.

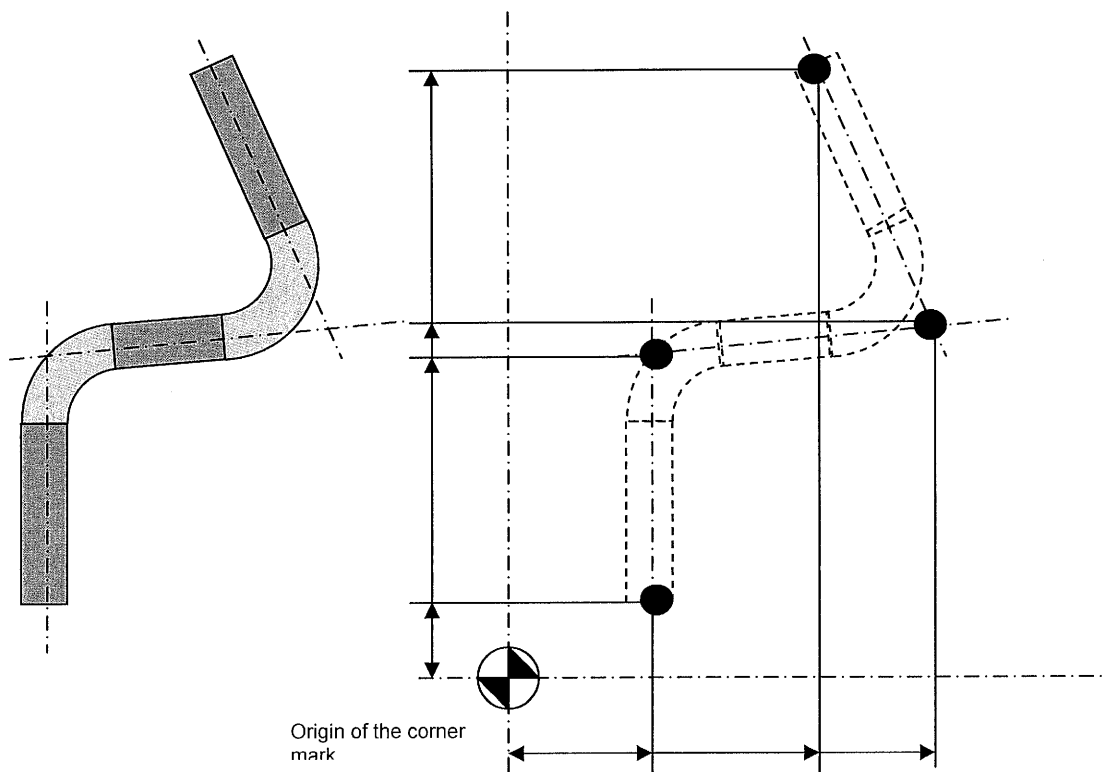
The pieces are generally defined by drawings (plans).

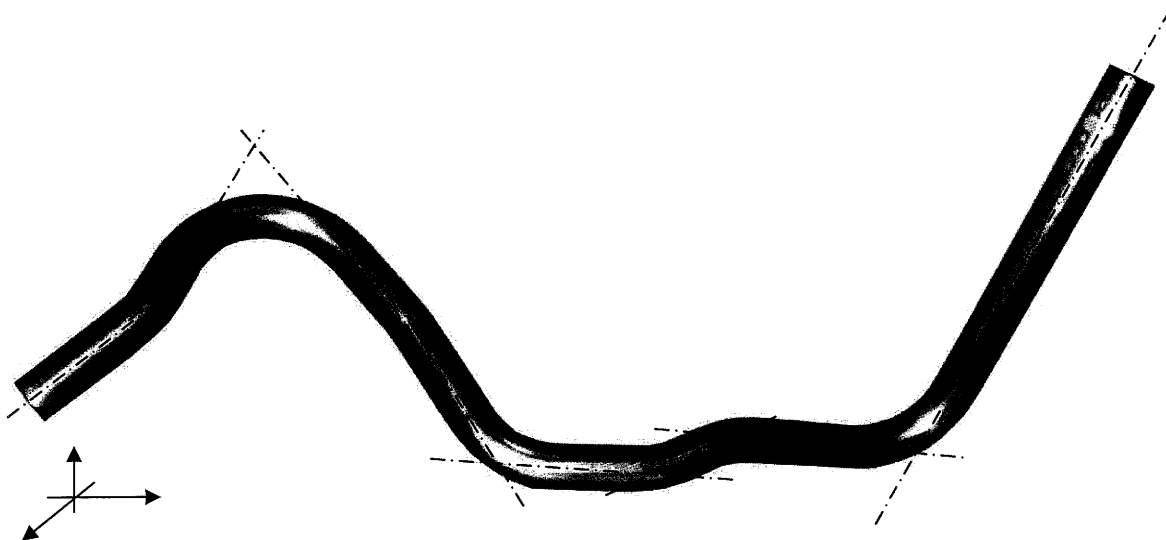
The quotation of these drawings is made within reference norms.

They define the positions of the axle of the tube cylinders (right segments).

They provide the coordinates of the points of intersection of the right parts as well as the two extremities, defined by the plan of extremity of the tube and its axle.

Comment : these segments are often associated with vectors.





This method of definition is correct in mechanics but it cannot be used by a machine bender.

Classical machine benders create bends (corners) one after another, a positioning system (for example a trolley) positions the tube in a polar mode (corners).

The Cartesian quotation system is called **X Y Z**.

In order to be used by a bender, the Cartesian quotation system must be converted towards a polar quotation.

The polar system defines the Lengths of rotation (or orientation) and the angles of bending.

The polar quotation system is called **L R A**.

It corresponds with the positioning axle of the machine and therefore it can be used in a bending programme that defines positioning of the numerical machine axle.

The machine axles are respectively **X B A**.

X for **lengths**.

B for **rotations**.

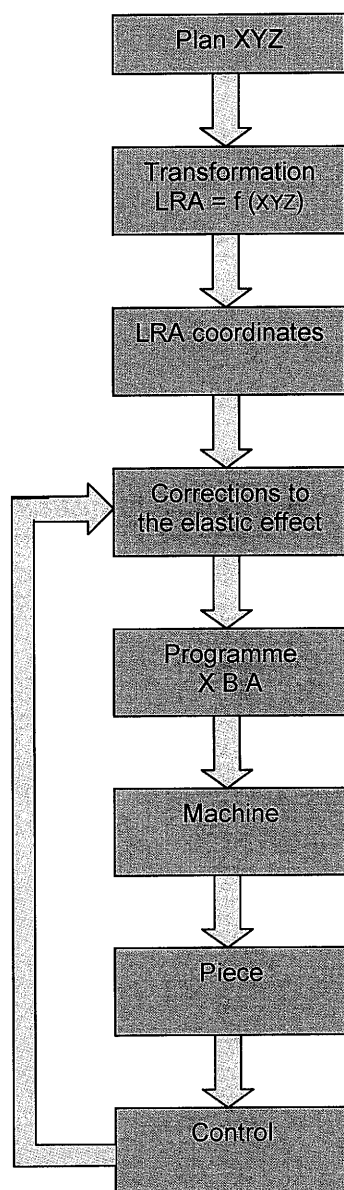
A for the **bending** angles.

This is one of the difficulties of the bending technique, the definition of pieces being in a Cartesian system and the bending programmes in a polar system. Conversion from one system to another is very difficult to imagine. It requires the assistance of computers.

Upon use of classical machine tooling (working) the path of the tools is generally compliant with the geometry of the pieces. If metals are worked for shaping, the path of the tools (programme) is different from the geometry of the pieces due to the elasticity of the materials. The programmes are therefore affected by the correction values that compensate the differences due to elasticity of the metal.

An operator that has to make a piece must always remember these two principles.

Layout:



The X Y Z Cartesian system .

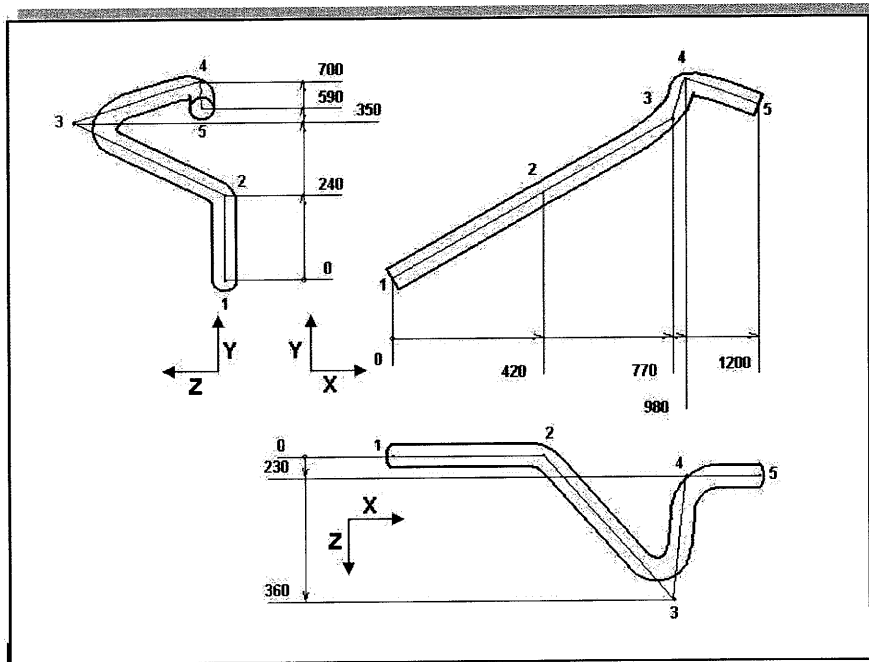
The positions of the points of intersection of the axes of the tube cylinders have a fixed origin.

Two other details define the geometry :

The diameter of the tube.

The radius at the axle of the bend.

The material and thickness characterise the piece but not its geometry .



The coordinates are generally presented in the form of a table :

| Piece ref. : Test | | | | |
|-------------------|------|-----------|-----|----------|
| Diameter | | Thickness | | Material |
| 50 | | 2 | | 1.4510 |
| Point | X | Y | Z | Ra |
| 1 | 0 | 0 | 0 | - |
| 2 | 420 | 240 | 0 | 90 |
| 3 | 770 | 350 | 360 | 90 |
| 4 | 980 | 700 | 23 | 90 |
| 5 | 1200 | 590 | 23 | - |

L R A, Lengths

Straight parts (cylindrical) of the piece.

They correspond with the lengths included between the end of the tube and the start of the first bend.

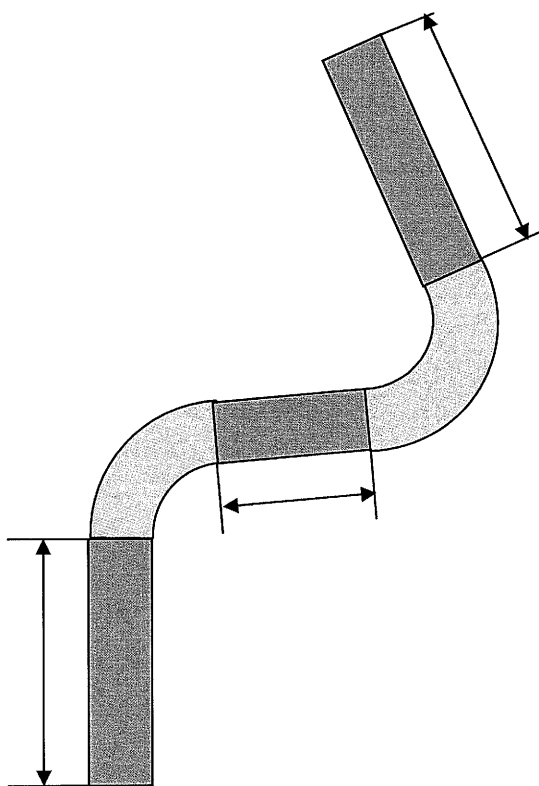
The end of one bend and the beginning of the next one.

The end of the last bend and the end of the tube.

Lengths are quoted in mm.

The lower limit is slightly negative.

There is no theoretical upper limit.



L R A, Rotations

This is the angle formed by the plans of the two subsequent bends.

It is quoted in degrees (°).

The reference is the bend of the weakest row (n) up until the next plan (n+1).

This angle ranges between 0 and 360°.

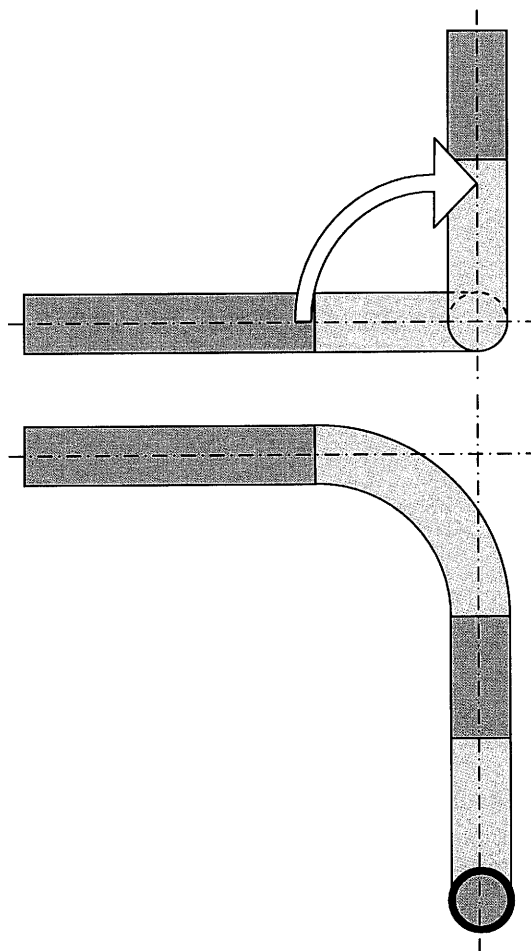
Conventionally, the angles are quoted at between -180° and +180°.

The positive direction is the trigonometric direction (anti-clockwise).

Therefore :

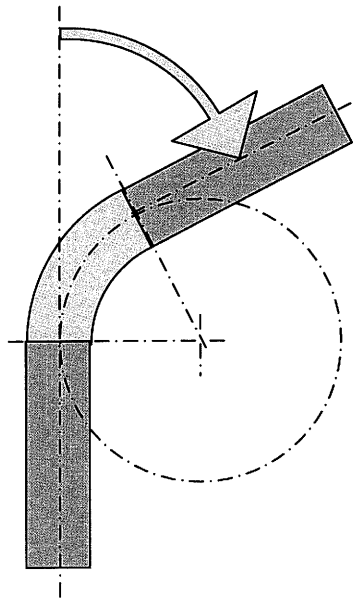
The minimum theoretical value is -180°.

The maximum theoretical value is +180°.

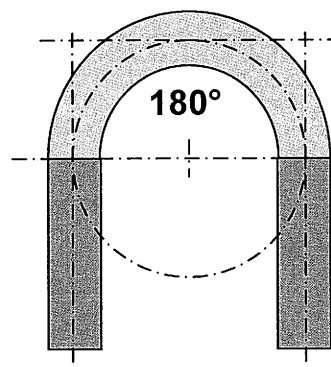
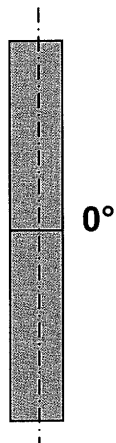


L R A , Bending angle.

It corresponds to the angle formed by two subsequent straight parts.
It is quoted in degrees (°).



On classical bending machines it ranges between 0° and 180°

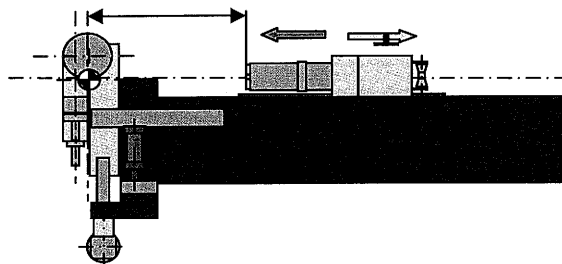
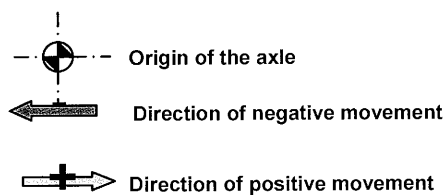


Relationship between the Lengths, Rotations, Angle and axes of machine positioning.

Lengths

The lengths are defined by the position of the linear axle of the trolley
The tube is immobilised on the trolley by pliers.

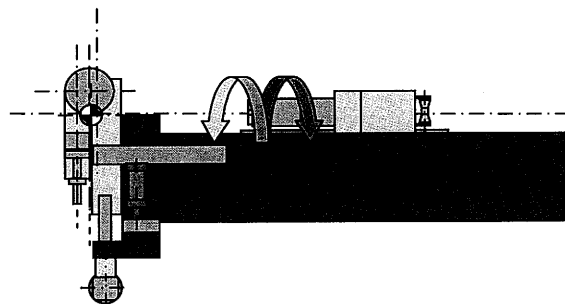
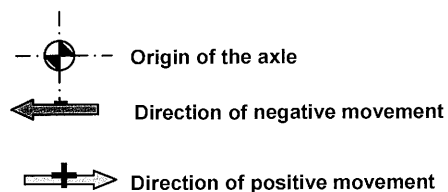
Axle X linear trolley.



Orientation

Orientation is defined by the position of the rotation axle on the trolley

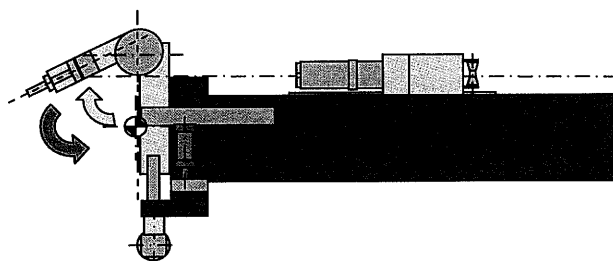
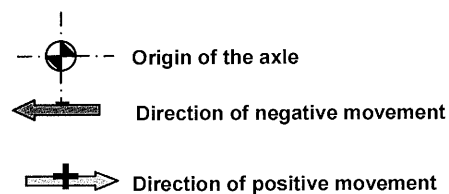
Axle B Orientation.



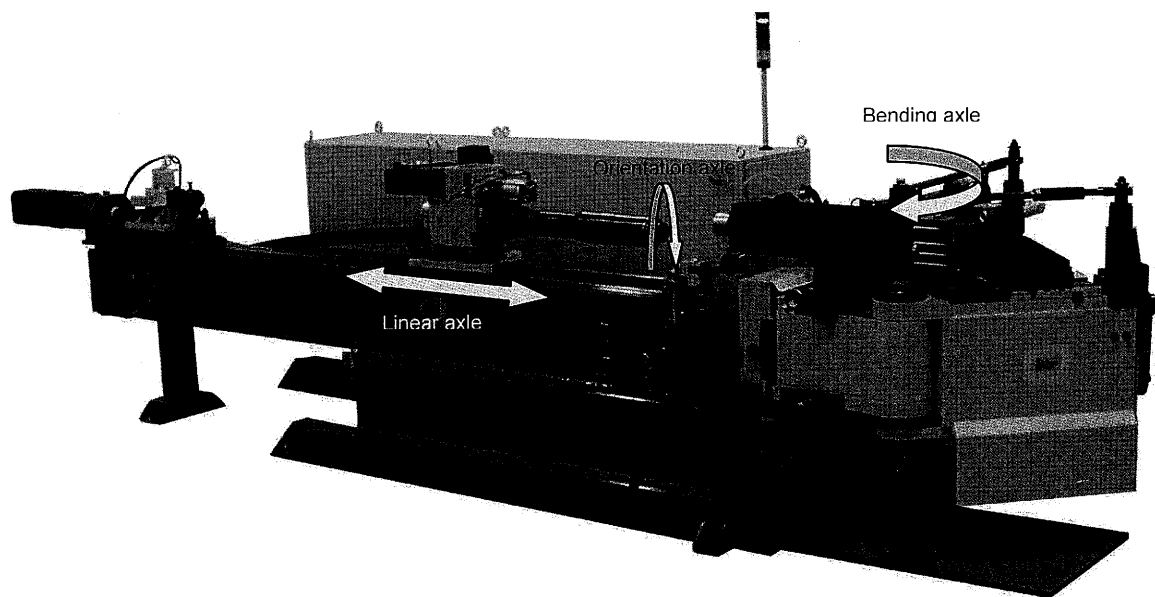
Bending angles

The bending angles are defined by the position of the rotation axle on the bending arm.

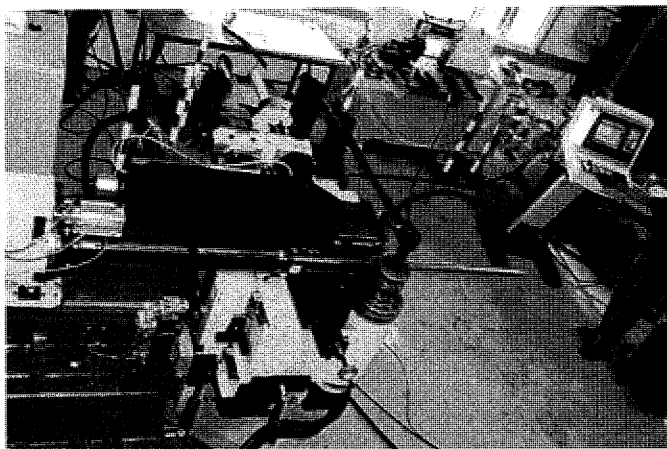
Axle A Bending.



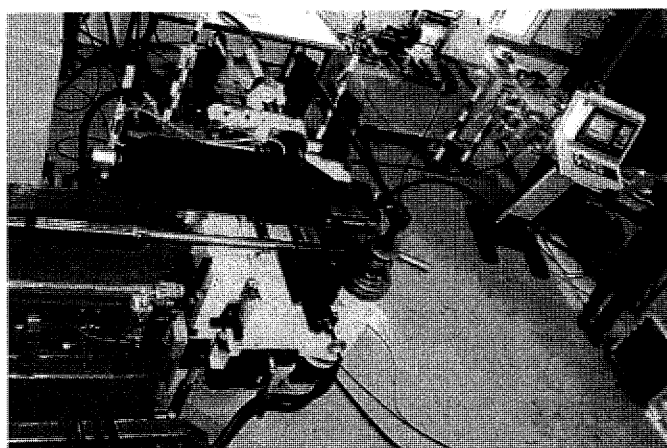
Axles of machine positioning



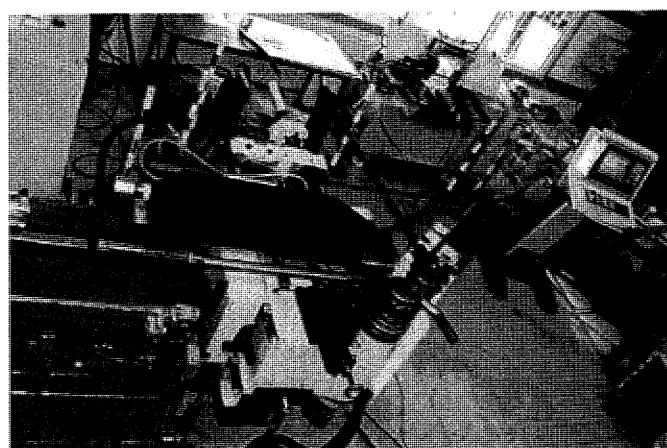
Working cycle of a bender



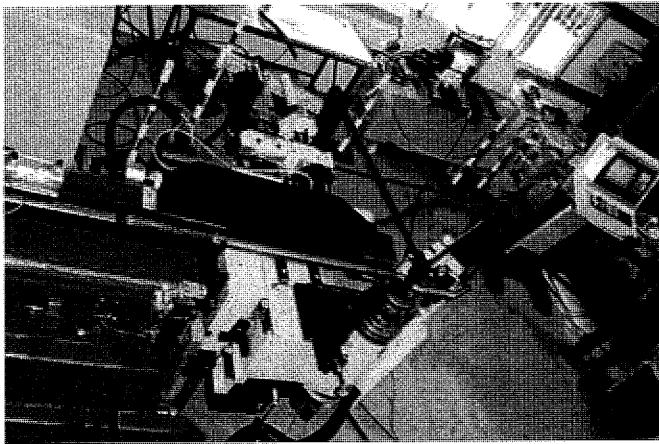
Introduction of the straight tube



Positioning and creation of the first bend



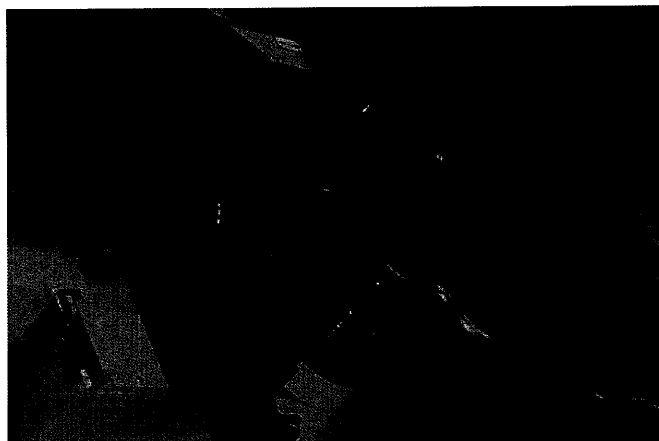
Positioning and creation of the second bend



Positioning and creation of the third bend



Positioning and creation of bend n.



Positioning and creation of bend x

Effect of elasticity on the bending angles.

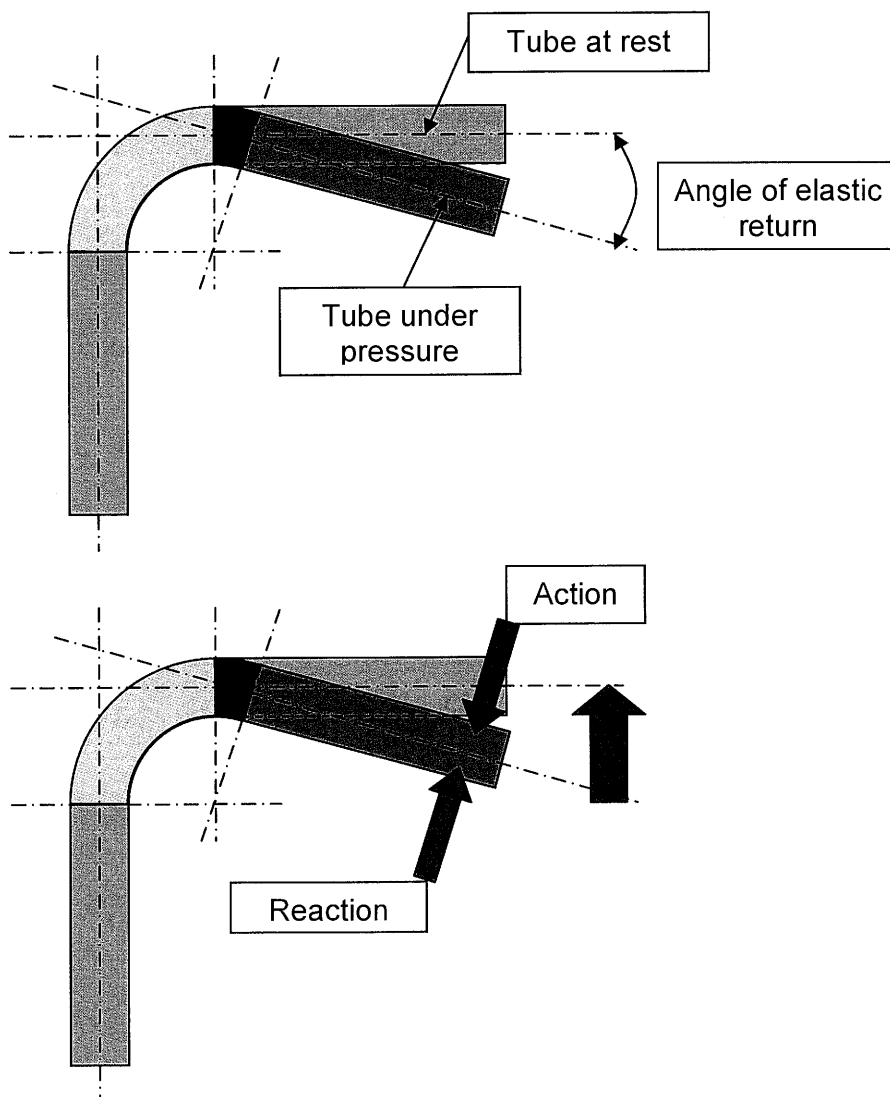
Having created the bend, the tube is under pressure. The action applied to the tube generates a reaction that opposes the action that has created it.

Once freed (opening of the vice) it tends to return to its original shape (straight).

In this way the bending corner created on the tube is still lower than the deformation that has caused it.

The yellow bending area is an area of plastic deformation.

The blue bending area is in an area of elastic deformation (and therefore it tends to return to its initial shape).



The elastic return angle on the bends is always negative

The elastic return angle depends on the following factors:

- Diameter of the tube.
- Thickness of the tube.
- Bending radius.
- Material of the tube.
- Adjustment factors:
 - o Type of bending technique used.
 - o Greasing (friction coefficient)
 - o Tool adjustment.
 - o Machine operation.
 - o Temperature, hygrometry ?

In order to quantify the elastic return angle and to anticipate deformation to be applied to the tube to create a bend at a given value, an empirical formula should be used. The equation of a right bend is therefore:

$$A = (a \times \text{Ang}) + b$$

A = angle of rotation of the bending arm.

Ang = angle achieved on the tube after opening.

a = proportional coefficient.

b = constant coefficient

$$A = (a \times \text{Ang}) + b$$

$$A = (a \times \text{Ang}) + b$$

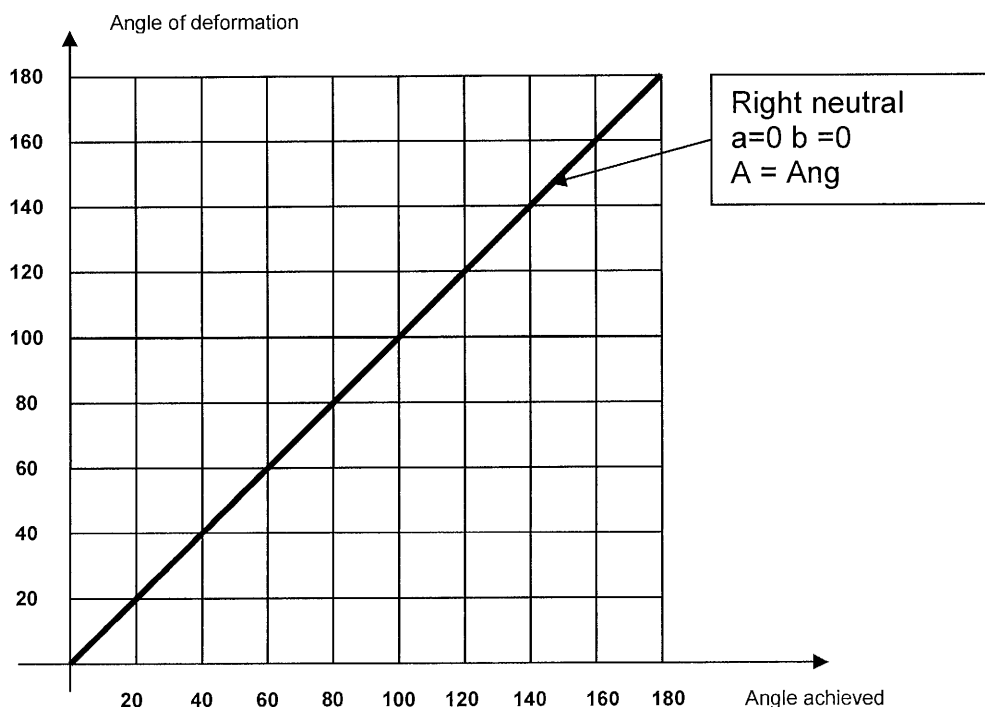
$$A = (a \times \text{Ang}) + b$$

$$A = (a \times \text{Ang}) + b$$

a and b are the coefficients that characterise the application.

NB : why the equation of a right bend, this is the easiest equation that corresponds to tests carried out within a chosen tolerance.

By using this formula, if the coefficients a and b are known, the deformation to be applied is determined (angle of rotation of the arm) in order to achieve a given bend value.



Definition of coefficients a and b.

Two angles of deformation are made on the tube (rotation of the bending arm) of distant values.

The angles most commonly used are 20 and 120°.

The corresponding angles achieved on the tube are measured using an angle measurer for example.

Two points are achieved, allowing for calculation of the right coefficients:

$$A(20) = a \times \text{Ang}(20) + b$$

$$A(120) = a \times \text{Ang}(120) + b$$

$$a = (A(\text{strong}) - A(\text{weak})) / (\text{Ang}(\text{strong}) - \text{Ang}(\text{weak}))$$

For 20 and 120°

$$a = 100 / (\text{Ang}(120) - \text{Ang}(20))$$

$$b = A(\text{strong}) - (a \times \text{Ang}(\text{strong}))$$

$$b = 120 - (a \times \text{Ang}(120))$$

Example for 20°, 18° is measured, for 120° 116° is measured on the tube

$$Aaa = 100 / (116 - 18) = 100 / 98 = 1.0204$$

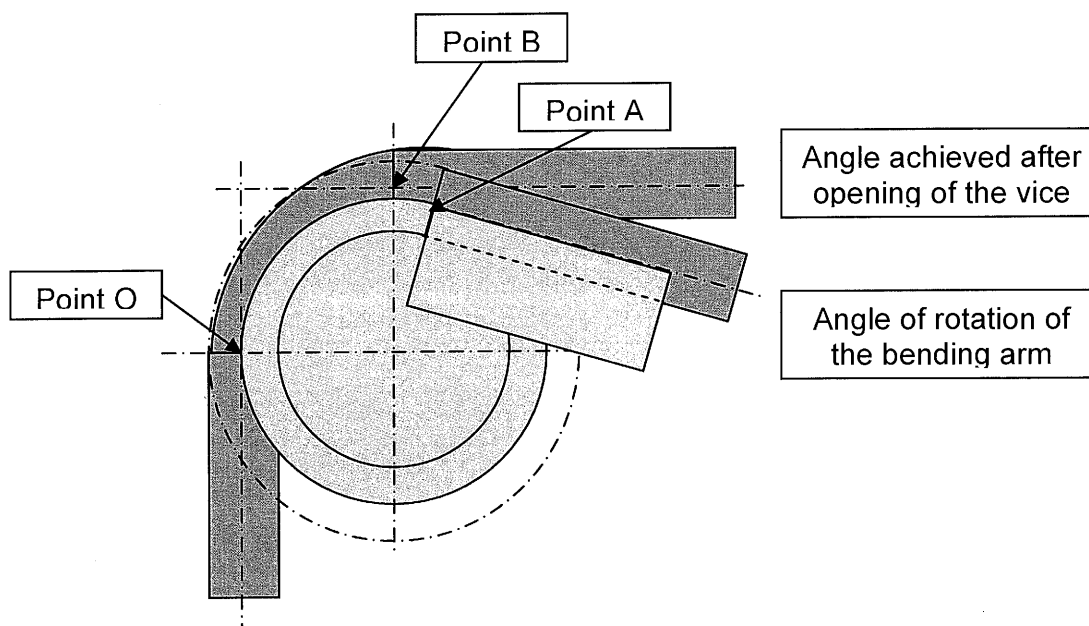
$$Bbbb = 120 - (1.0204 \times 116) = 1.63$$

The ratio on the angles of rotation of the bending arms and the angle achieved on the tube is :

$$A = (1.0204 \times \text{Ang}) + 1,63$$

A being different from the Ang (always higher).

Effects of elasticity on the bending radius.



Hypothesis of the neutral fibre on the tube remains constant :

Therefore:

A = angle of rotation of the bending arm

Ang = angle achieved on the tube after opening.

Ret = A - Ang

A = Ang + Ret

The arch OA is equivalent to the arch OB therefore :

OA = $2 \times \pi / 360 \times R_{\text{tool}} \times A$

OB = $2 \times \pi / 360 \times R_{\text{tube}} \times \text{Ang}$

Considering the start and the end of the bend, these two parts are in an area of elastic deformation.

The tube is wound onto the forming rollers but it returns to an almost straight shape once the stress has been removed (opening of the vice).

This angle b is called an elastic bending limit, that is to say that every possible deformation (rotation of the bending arm lower than the angle b) the tube maintains a straight form.

Real radius on the tube:

$R_{\text{tube}} = R_{\text{tool}} \times ((a \times \text{Ang}) + b) - (b \times R_{\text{tool}})$

$R_{\text{tube}} \times \text{Ang} = (R_{\text{tool}} \times a \times \text{Ang}) + (b \times R_{\text{tool}}) - (b \times R_{\text{tool}})$

$R_{\text{tube}} = a \times R_{\text{tool}}$

The radius achieved on the tube depends on the coefficient proportional to the correction on the bending angles.

THE BENDING RADIUS ACHIEVED IS STILL HIGHER THAN THE RADIUS OF THE TOOL

Correction of the geometry of the piece due to modification of the bending angles

It is worth adding a correction on the bending angles.

NB: this correction is not perfectly proportional and it depends on the curve of correction.

The coefficient is always above 1 :

The gap is not equivalent to the correction.

Example :

If the angle desired is 90°

The angle measured must be 88°

A correction of 2° will not create a permanente angle of deformation on the 90° tube but it will create a slightly lower deformation.

Example :

If the coefficient a is the following :

$a = 1.0204$

As the coefficient b has been overcome, the area of plastic deformation is no longer valid.

$2 = (1.024 \times \text{Ang})$

$\text{Ang} = 2 / 1.0204$

$\text{Ang} = 1,96$ which is very close to the physical reality but it is incorrect in theoretical terms.

The more the materials have an important factor, the more important the effect is.

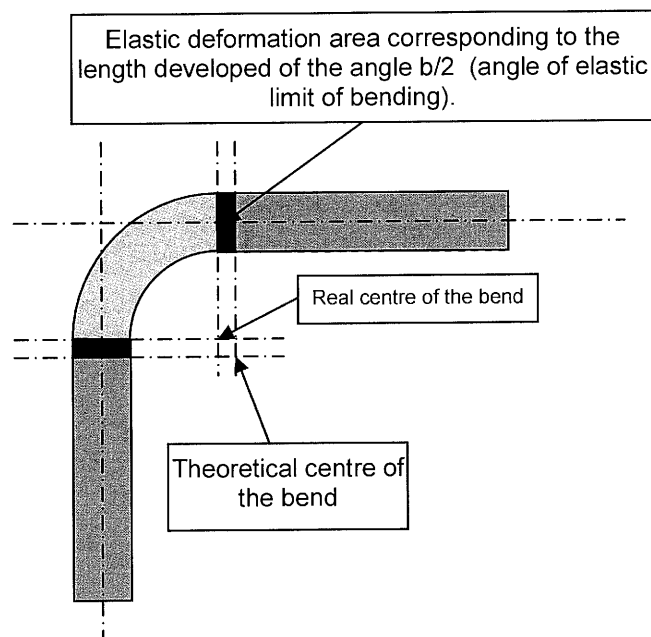
Correction of the geometry piece due to modifications to the bending radius.

Two separate effects are characterised :

Movement of the centre of the radius due to the effect of the angle b on the right of the bending correction.

An increase in the bending radius due to the coefficient on the right of the bending correction.

Movement of the radius centre :



Movement of the radius is:

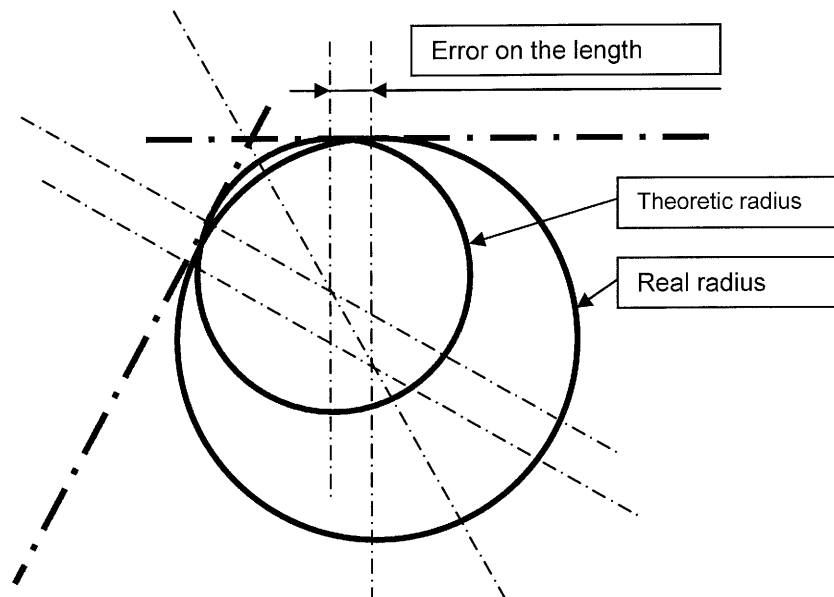
$$\Delta L = (2 \times \pi / 360) \times R_{\text{tool}} \times (b / 2)$$

This movement has a direct effect on the lengths.

Increase of the radius:

The bending radius achieved on the tube exceeds the radius of the tool.

$$R_{\text{bending}} = a \times R_{\text{tool}}$$



The error due to the difference of the radius is:

$$\Delta L = (R_{\text{cint}} - R_{\text{tool}}) \times \text{tg} (\text{Ang} / 2)$$

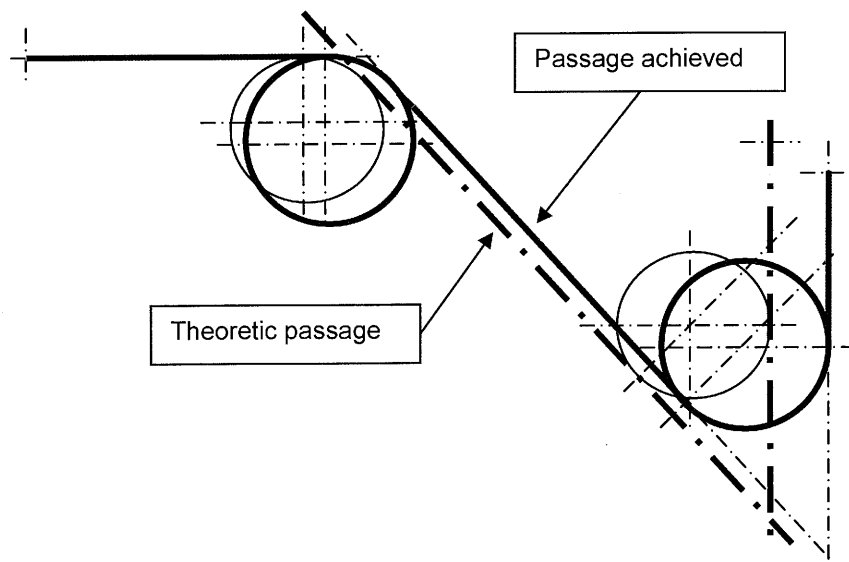
$$\Delta L = R_{\text{tool}} \times (a - 1) \times \text{tg} (\text{Ang} / 2)$$

The effect of increase and movement of the bending radius on the geometry of a piece.

If the lengths are not corrected, the geometry of the piece will be false.

The following result is achieved :

The errors are important (several mm).



By applying corrections to the lengths, therefore a reduction to the straight parts, the following result is achieved:

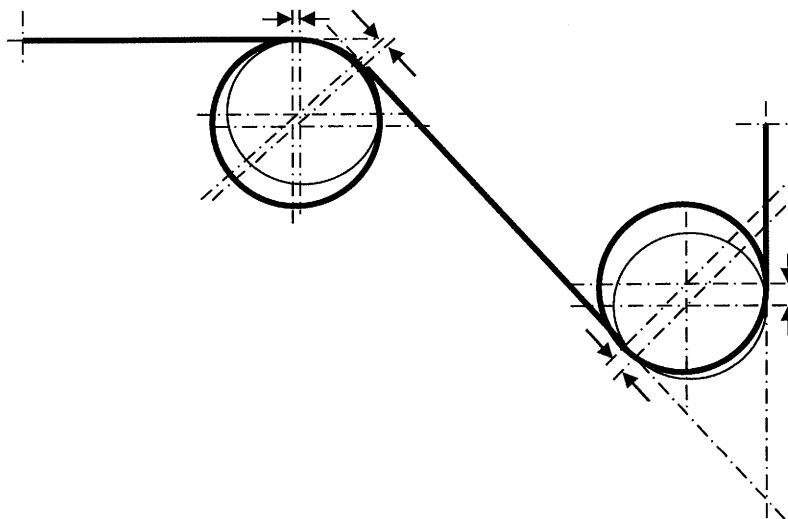
The values of corrections depend on several parameters :

Diameter, thickness, material of the tube.

Radius of bending, the bending technique used.

Tool adjustment.

Temperature, greasing etc...



Example of calculation of corrections:

Parameters: $a = 1,0309$ $b = 2,80$ Radius of the bend 100 mm

| L | R | A |
|--------|--------|-------|
| 100.00 | 0.00 | 60.00 |
| 200.00 | 180.00 | 45.00 |
| 300.00 | 0.00 | 0.00 |

Corrections due to angle b (annex 1) $2,80$ ra 100 : **4,9mm**

Difference on the bending radius coefficient a (annex 3) $a = 1,0309$ ra 100 : **3,09 mm**

Tg angle / 2 (Annex 2)

60° : 0,577

45° : 0,414

Corrections due to the difference on the bending radius:

60° : $3,09 \times 0,577 =$ **1,78 mm**

45° : $3,09 \times 0,414 =$ **1,28 mm**

Length correction 1 = $4,09 + 1,78 =$ **5,87 mm**

Length correction 2 = $4,09 + 1,78 + 1,28 =$ **7,15 mm**

If an angle of the piece is 140° the correction due to the difference on the bending radius is therefore :

120° : Tg (A/2) = 1,732

120° : $3,09 \times 1,732 =$ **5,35 mm**

If an angle of the piece is 160° the correction due to the difference on the bending radius is therefore:

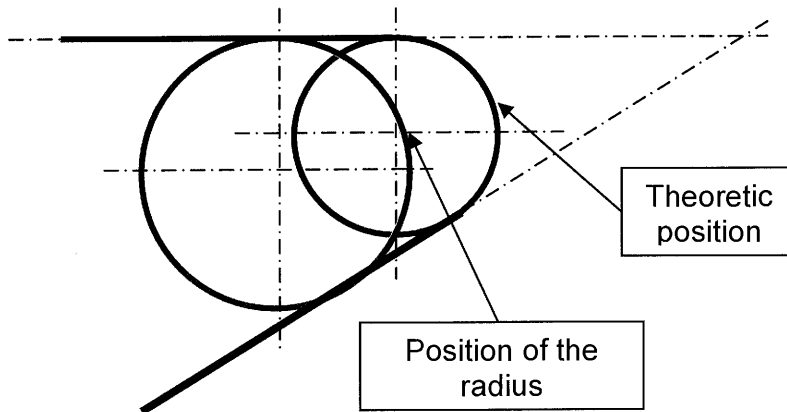
160° : Tg (A/2) = 5,671

160° : $3,09 \times 5,671 =$ **17.52 mm**

Comment:

The influence of correction due to the difference on the bending radius is very important when the bending angles are high.

It is always possible (except for angles close to 180°) to respect the passage of straight parts, but it is impossible to respect the position of the bends.



The only solution is to reduce the radius of the tool in order to compensate the difference on the radius of the tube.

In the previous example, it is worth using a bending shape of $100 - 3,09 = 96.91$ mm

INFLUENCE OF EXTENSION IN THE BENDS ON THE GEOMETRY OF THE TUBE

In each bend the tube extends.

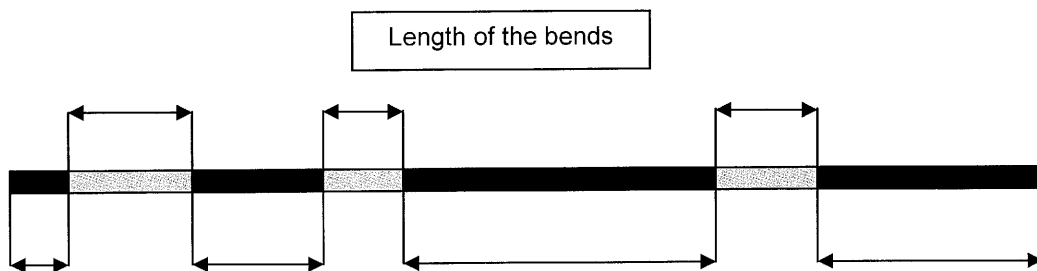
As the material extends the neutral fibre (axis) of the tube moves (thinning of the extrados and thickening of the intrados).

This extension alters (in a classical positioning system) the length of the tube after bending.

First effect: the length of the tube to create a piece is different from the theoretic length.

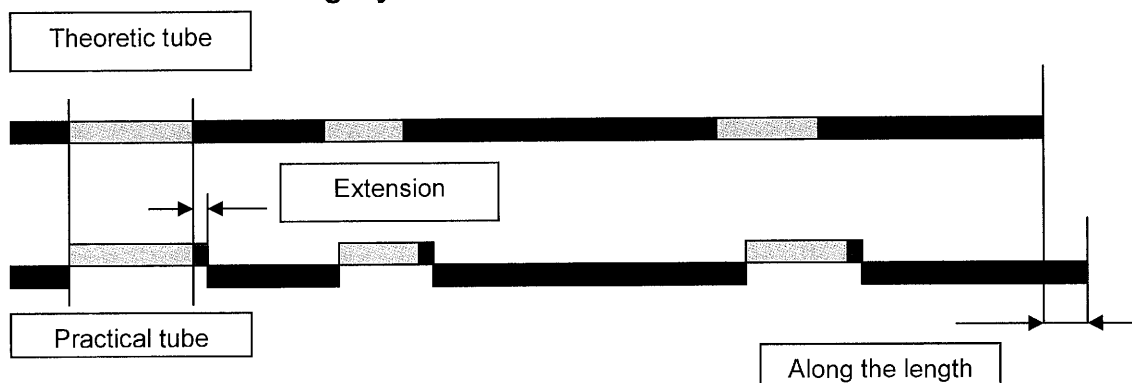
Furthermore, according to the material, the bending conditions etc. the length of the tube changes or creates geometry errors.

The following diagram represents a bent piece:



If the tube is extended compared with the theoretic development, a shorter tube should be used to create a compliant piece.

Therefore the following layout is created:

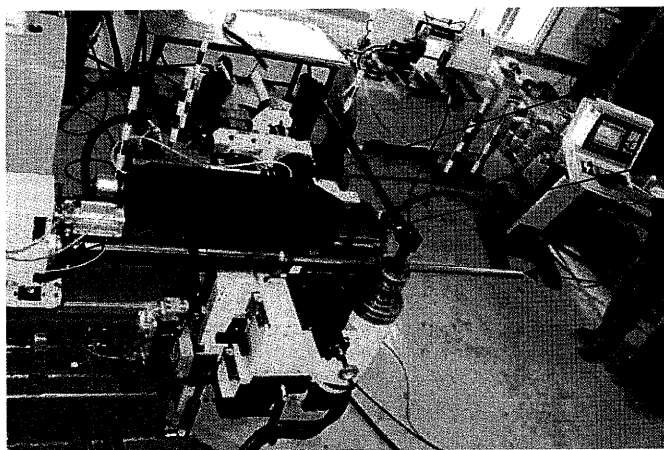


The extension of the tube in the bends is difficult to control, therefore considering the method of positioning of the benders (technology) the last right part is changed according to the differences in extension of the previous bends.

The more bends a piece has (the total amount of the angles) the more errors there will be on the straight part.

The first straight part will only be affected by the offset of the centre of the radius due to the effect of angle b of the bending correction.

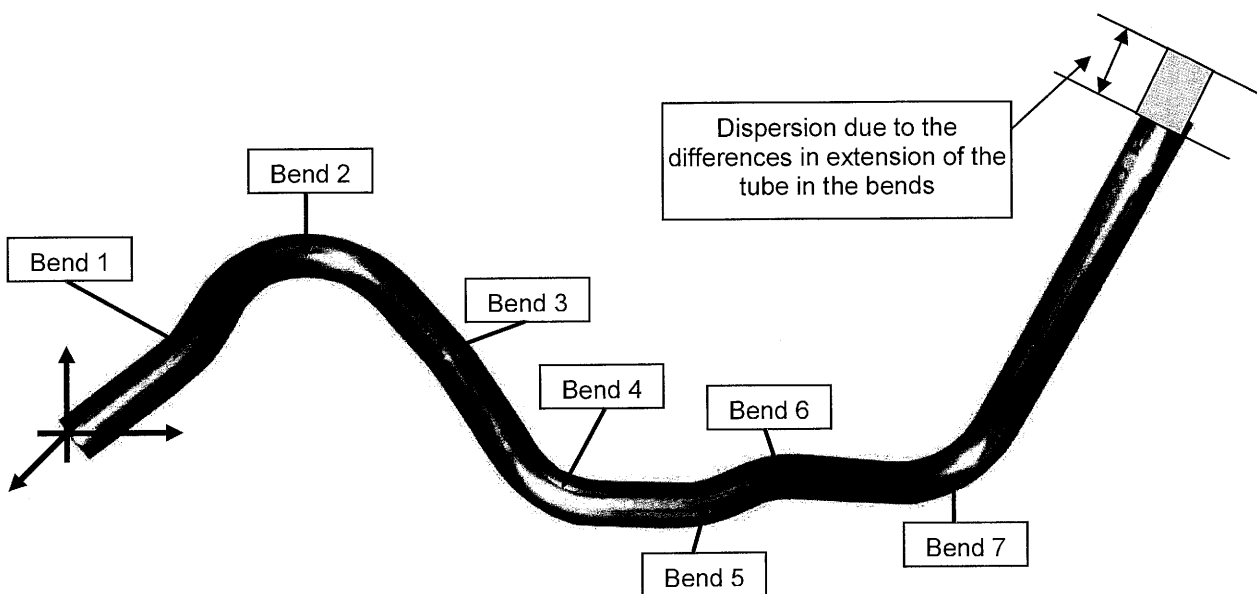
This rather weak value compared with other corrections allows for the end of the tube located on the straight part of the first bend to be used as a reference (origin).



Positioning trolley

Clamp

Reference of the piece



Annex 1 Corrections to be made according to angle b

| R/b | 1 | 1,2 | 1,4 | 1,6 | 1,8 | 2 | 2,2 | 2,4 | 2,6 | 2,8 | 3 | 3,2 | 3,4 | 3,6 | 3,8 | 4 | 4,2 | 4,4 | 4,6 | 4,8 | 5 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|
| 10 | 0,2 | 0,2 | 0,2 | 0,3 | 0,3 | 0,3 | 0,4 | 0,4 | 0,5 | 0,5 | 0,5 | 0,6 | 0,6 | 0,6 | 0,7 | 0,7 | 0,7 | 0,8 | 0,8 | 0,8 | 0,9 |
| 15 | 0,3 | 0,3 | 0,4 | 0,4 | 0,5 | 0,5 | 0,6 | 0,6 | 0,7 | 0,7 | 0,8 | 0,8 | 0,9 | 0,9 | 1,0 | 1,0 | 1,1 | 1,2 | 1,2 | 1,3 | 1,3 |
| 20 | 0,3 | 0,4 | 0,5 | 0,6 | 0,6 | 0,7 | 0,8 | 0,8 | 0,9 | 1,0 | 1,0 | 1,1 | 1,2 | 1,3 | 1,3 | 1,4 | 1,5 | 1,5 | 1,6 | 1,7 | 1,7 |
| 25 | 0,4 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 | 1,0 | 1,0 | 1,1 | 1,2 | 1,3 | 1,4 | 1,5 | 1,6 | 1,7 | 1,7 | 1,8 | 1,9 | 2,0 | 2,1 | 2,2 |
| 30 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 | 1,0 | 1,2 | 1,3 | 1,4 | 1,5 | 1,6 | 1,7 | 1,8 | 1,9 | 2,0 | 2,1 | 2,2 | 2,3 | 2,4 | 2,5 | 2,6 |
| 35 | 0,6 | 0,7 | 0,9 | 1,0 | 1,1 | 1,2 | 1,3 | 1,5 | 1,6 | 1,7 | 1,8 | 2,0 | 2,1 | 2,2 | 2,3 | 2,4 | 2,6 | 2,7 | 2,8 | 2,9 | 3,1 |
| 40 | 0,7 | 0,8 | 1,0 | 1,1 | 1,3 | 1,4 | 1,5 | 1,7 | 1,8 | 2,0 | 2,1 | 2,2 | 2,4 | 2,5 | 2,7 | 2,8 | 2,9 | 3,1 | 3,2 | 3,4 | 3,5 |
| 45 | 0,8 | 0,9 | 1,1 | 1,3 | 1,4 | 1,6 | 1,7 | 1,9 | 2,0 | 2,2 | 2,4 | 2,5 | 2,7 | 2,8 | 3,0 | 3,1 | 3,3 | 3,5 | 3,6 | 3,8 | 3,9 |
| 50 | 0,9 | 1,0 | 1,2 | 1,4 | 1,6 | 1,7 | 1,9 | 2,1 | 2,3 | 2,4 | 2,6 | 2,8 | 3,0 | 3,1 | 3,3 | 3,5 | 3,7 | 3,8 | 4,0 | 4,2 | 4,4 |
| 55 | 1,0 | 1,2 | 1,3 | 1,5 | 1,7 | 1,9 | 2,1 | 2,3 | 2,5 | 2,7 | 2,9 | 3,1 | 3,3 | 3,5 | 3,6 | 3,8 | 4,0 | 4,2 | 4,4 | 4,6 | 4,8 |
| 60 | 1,0 | 1,3 | 1,5 | 1,7 | 1,9 | 2,1 | 2,3 | 2,5 | 2,7 | 2,9 | 3,1 | 3,4 | 3,6 | 3,8 | 4,0 | 4,2 | 4,4 | 4,6 | 4,8 | 5,0 | 5,2 |
| 65 | 1,1 | 1,4 | 1,6 | 1,8 | 2,0 | 2,3 | 2,5 | 2,7 | 2,9 | 3,2 | 3,4 | 3,6 | 3,9 | 4,1 | 4,3 | 4,5 | 4,8 | 5,0 | 5,2 | 5,4 | 5,7 |
| 70 | 1,2 | 1,5 | 1,7 | 2,0 | 2,2 | 2,4 | 2,7 | 2,9 | 3,2 | 3,4 | 3,7 | 3,9 | 4,2 | 4,4 | 4,6 | 4,9 | 5,1 | 5,4 | 5,6 | 5,9 | 6,1 |
| 75 | 1,3 | 1,6 | 1,8 | 2,1 | 2,4 | 2,6 | 2,9 | 3,1 | 3,4 | 3,7 | 3,9 | 4,2 | 4,5 | 4,7 | 5,0 | 5,2 | 5,5 | 5,8 | 6,0 | 6,3 | 6,5 |
| 80 | 1,4 | 1,7 | 2,0 | 2,2 | 2,5 | 2,8 | 3,1 | 3,4 | 3,6 | 3,9 | 4,2 | 4,5 | 4,7 | 5,0 | 5,3 | 5,6 | 5,9 | 6,1 | 6,4 | 6,7 | 7,0 |
| 85 | 1,5 | 1,8 | 2,1 | 2,4 | 2,7 | 3,0 | 3,3 | 3,6 | 3,9 | 4,2 | 4,5 | 4,7 | 5,0 | 5,3 | 5,6 | 5,9 | 6,2 | 6,5 | 6,8 | 7,1 | 7,4 |
| 90 | 1,6 | 1,9 | 2,2 | 2,5 | 2,8 | 3,1 | 3,5 | 3,8 | 4,1 | 4,4 | 4,7 | 5,0 | 5,3 | 5,7 | 6,0 | 6,3 | 6,6 | 6,9 | 7,2 | 7,5 | 7,9 |
| 95 | 1,7 | 2,0 | 2,3 | 2,7 | 3,0 | 3,3 | 3,6 | 4,0 | 4,3 | 4,6 | 5,0 | 5,3 | 5,6 | 6,0 | 6,3 | 6,6 | 7,0 | 7,3 | 7,6 | 8,0 | 8,3 |
| 100 | 1,7 | 2,1 | 2,4 | 2,8 | 3,1 | 3,5 | 3,8 | 4,2 | 4,5 | 4,9 | 5,2 | 5,6 | 5,9 | 6,3 | 6,6 | 7,0 | 7,3 | 7,7 | 8,0 | 8,4 | 8,7 |
| 105 | 1,8 | 2,2 | 2,6 | 2,9 | 3,3 | 3,7 | 4,0 | 4,4 | 4,8 | 5,1 | 5,5 | 5,9 | 6,2 | 6,6 | 7,0 | 7,3 | 7,7 | 8,1 | 8,4 | 8,8 | 9,2 |
| 110 | 1,9 | 2,3 | 2,7 | 3,1 | 3,5 | 3,8 | 4,2 | 4,6 | 5,0 | 5,4 | 5,8 | 6,1 | 6,5 | 6,9 | 7,3 | 7,7 | 8,1 | 8,4 | 8,8 | 9,2 | 9,6 |
| 115 | 2,0 | 2,4 | 2,8 | 3,2 | 3,6 | 4,0 | 4,4 | 4,8 | 5,2 | 5,6 | 6,0 | 6,4 | 6,8 | 7,2 | 7,6 | 8,0 | 8,4 | 8,8 | 9,2 | 9,6 | 10,0 |
| 120 | 2,1 | 2,5 | 2,9 | 3,4 | 3,8 | 4,2 | 4,6 | 5,0 | 5,4 | 5,9 | 6,3 | 6,7 | 7,1 | 7,5 | 8,0 | 8,4 | 8,8 | 9,2 | 9,6 | 10,1 | 10,5 |
| 125 | 2,2 | 2,6 | 3,1 | 3,5 | 3,9 | 4,4 | 4,8 | 5,2 | 5,7 | 6,1 | 6,5 | 7,0 | 7,4 | 7,9 | 8,3 | 8,7 | 9,2 | 9,6 | 10,0 | 10,5 | 10,9 |
| 130 | 2,3 | 2,7 | 3,2 | 3,6 | 4,1 | 4,5 | 5,0 | 5,4 | 5,9 | 6,4 | 6,8 | 7,3 | 7,7 | 8,2 | 8,6 | 9,1 | 9,5 | 10,0 | 10,4 | 10,9 | 11,3 |
| 135 | 2,4 | 2,8 | 3,3 | 3,8 | 4,2 | 4,7 | 5,2 | 5,7 | 6,1 | 6,6 | 7,1 | 7,5 | 8,0 | 8,5 | 9,0 | 9,4 | 9,9 | 10,4 | 10,8 | 11,3 | 11,8 |
| 140 | 2,4 | 2,9 | 3,4 | 3,9 | 4,4 | 4,9 | 5,4 | 5,9 | 6,4 | 6,8 | 7,3 | 7,8 | 8,3 | 8,8 | 9,3 | 9,8 | 10,3 | 10,8 | 11,2 | 11,7 | 12,2 |
| 145 | 2,5 | 3,0 | 3,5 | 4,0 | 4,6 | 5,1 | 5,6 | 6,1 | 6,6 | 7,1 | 7,6 | 8,1 | 8,6 | 9,1 | 9,6 | 10,1 | 10,6 | 11,1 | 11,6 | 12,1 | 12,7 |
| 150 | 2,6 | 3,1 | 3,7 | 4,2 | 4,7 | 5,2 | 5,8 | 6,3 | 6,8 | 7,3 | 7,9 | 8,4 | 8,9 | 9,4 | 9,9 | 10,5 | 11,0 | 11,5 | 12,0 | 12,6 | 13,1 |

Annex 2 : bending angle tangent divided by 2
 $\text{tg} (\text{Ang} / 2)$

| Ang | TgA/2 |
|-----|--------|
| 5 | 0,044 |
| 10 | 0,087 |
| 15 | 0,132 |
| 20 | 0,176 |
| 25 | 0,222 |
| 30 | 0,268 |
| 35 | 0,315 |
| 40 | 0,364 |
| 45 | 0,414 |
| 50 | 0,466 |
| 55 | 0,521 |
| 60 | 0,577 |
| 65 | 0,637 |
| 70 | 0,700 |
| 75 | 0,767 |
| 80 | 0,839 |
| 85 | 0,916 |
| 90 | 1,000 |
| 95 | 1,091 |
| 100 | 1,192 |
| 105 | 1,303 |
| 110 | 1,428 |
| 115 | 1,570 |
| 120 | 1,732 |
| 125 | 1,921 |
| 130 | 2,144 |
| 135 | 2,414 |
| 140 | 2,747 |
| 145 | 3,171 |
| 150 | 3,732 |
| 155 | 4,510 |
| 160 | 5,671 |
| 165 | 7,594 |
| 170 | 11,427 |
| 175 | 22,890 |

Annex 3 Gap between the bending radius according to the coefficient a

| delta | 0,5 | 1 | 1,5 | 2 | 2,5 | 3 | 3,5 | 4 | 4,5 | 5 | 5,5 | 6 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| a | 1,0050 | 1,0101 | 1,0152 | 1,0204 | 1,0256 | 1,0309 | 1,0363 | 1,0417 | 1,0471 | 1,0526 | 1,0582 | 1,0638 |
| Radius | | | | | | | | | | | | |
| 10 | 0,05 | 0,10 | 0,15 | 0,20 | 0,26 | 0,31 | 0,36 | 0,42 | 0,47 | 0,53 | 0,58 | 0,64 |
| 15 | 0,08 | 0,15 | 0,23 | 0,31 | 0,38 | 0,46 | 0,54 | 0,63 | 0,71 | 0,79 | 0,87 | 0,96 |
| 20 | 0,10 | 0,20 | 0,30 | 0,41 | 0,51 | 0,62 | 0,73 | 0,83 | 0,94 | 1,05 | 1,16 | 1,28 |
| 25 | 0,13 | 0,25 | 0,38 | 0,51 | 0,64 | 0,77 | 0,91 | 1,04 | 1,18 | 1,32 | 1,46 | 1,60 |
| 30 | 0,15 | 0,30 | 0,46 | 0,61 | 0,77 | 0,93 | 1,09 | 1,25 | 1,41 | 1,58 | 1,75 | 1,91 |
| 35 | 0,18 | 0,35 | 0,53 | 0,71 | 0,90 | 1,08 | 1,27 | 1,46 | 1,65 | 1,84 | 2,04 | 2,23 |
| 40 | 0,20 | 0,40 | 0,61 | 0,82 | 1,02 | 1,24 | 1,45 | 1,67 | 1,88 | 2,10 | 2,33 | 2,55 |
| 45 | 0,23 | 0,45 | 0,68 | 0,92 | 1,15 | 1,39 | 1,63 | 1,88 | 2,12 | 2,37 | 2,62 | 2,87 |
| 50 | 0,25 | 0,51 | 0,76 | 1,02 | 1,28 | 1,55 | 1,82 | 2,09 | 2,36 | 2,63 | 2,91 | 3,19 |
| 55 | 0,28 | 0,56 | 0,84 | 1,12 | 1,41 | 1,70 | 2,00 | 2,29 | 2,59 | 2,89 | 3,20 | 3,51 |
| 60 | 0,30 | 0,61 | 0,91 | 1,22 | 1,54 | 1,85 | 2,18 | 2,50 | 2,83 | 3,16 | 3,49 | 3,83 |
| 65 | 0,33 | 0,66 | 0,99 | 1,33 | 1,66 | 2,01 | 2,36 | 2,71 | 3,06 | 3,42 | 3,78 | 4,15 |
| 70 | 0,35 | 0,71 | 1,06 | 1,43 | 1,79 | 2,16 | 2,54 | 2,92 | 3,30 | 3,68 | 4,07 | 4,47 |
| 75 | 0,38 | 0,76 | 1,14 | 1,53 | 1,92 | 2,32 | 2,72 | 3,13 | 3,53 | 3,95 | 4,37 | 4,79 |
| 80 | 0,40 | 0,81 | 1,22 | 1,63 | 2,05 | 2,47 | 2,90 | 3,34 | 3,77 | 4,21 | 4,66 | 5,10 |
| 85 | 0,43 | 0,86 | 1,29 | 1,73 | 2,18 | 2,63 | 3,09 | 3,54 | 4,00 | 4,47 | 4,95 | 5,42 |
| 90 | 0,45 | 0,91 | 1,37 | 1,84 | 2,30 | 2,78 | 3,27 | 3,75 | 4,24 | 4,73 | 5,24 | 5,74 |
| 95 | 0,48 | 0,96 | 1,44 | 1,94 | 2,43 | 2,94 | 3,45 | 3,96 | 4,47 | 5,00 | 5,53 | 6,06 |
| 100 | 0,50 | 1,01 | 1,52 | 2,04 | 2,56 | 3,09 | 3,63 | 4,17 | 4,71 | 5,26 | 5,82 | 6,38 |
| 105 | 0,53 | 1,06 | 1,60 | 2,14 | 2,69 | 3,24 | 3,81 | 4,38 | 4,95 | 5,52 | 6,11 | 6,70 |
| 110 | 0,55 | 1,11 | 1,67 | 2,24 | 2,82 | 3,40 | 3,99 | 4,59 | 5,18 | 5,79 | 6,40 | 7,02 |
| 115 | 0,58 | 1,16 | 1,75 | 2,35 | 2,94 | 3,55 | 4,17 | 4,80 | 5,42 | 6,05 | 6,69 | 7,34 |
| 120 | 0,60 | 1,21 | 1,82 | 2,45 | 3,07 | 3,71 | 4,36 | 5,00 | 5,65 | 6,31 | 6,98 | 7,66 |
| 125 | 0,63 | 1,26 | 1,90 | 2,55 | 3,20 | 3,86 | 4,54 | 5,21 | 5,89 | 6,58 | 7,28 | 7,98 |
| 130 | 0,65 | 1,31 | 1,98 | 2,65 | 3,33 | 4,02 | 4,72 | 5,42 | 6,12 | 6,84 | 7,57 | 8,29 |
| 135 | 0,68 | 1,36 | 2,05 | 2,75 | 3,46 | 4,17 | 4,90 | 5,63 | 6,36 | 7,10 | 7,86 | 8,61 |
| 140 | 0,70 | 1,41 | 2,13 | 2,86 | 3,58 | 4,33 | 5,08 | 5,84 | 6,59 | 7,36 | 8,15 | 8,93 |
| 145 | 0,73 | 1,46 | 2,20 | 2,96 | 3,71 | 4,48 | 5,26 | 6,05 | 6,83 | 7,63 | 8,44 | 9,25 |
| 150 | 0,75 | 1,52 | 2,28 | 3,06 | 3,84 | 4,64 | 5,45 | 6,26 | 7,07 | 7,89 | 8,73 | 9,57 |
| 155 | 0,78 | 1,57 | 2,36 | 3,16 | 3,97 | 4,79 | 5,63 | 6,46 | 7,30 | 8,15 | 9,02 | 9,89 |
| 160 | 0,80 | 1,62 | 2,43 | 3,26 | 4,10 | 4,94 | 5,81 | 6,67 | 7,54 | 8,42 | 9,31 | 10,21 |
| 165 | 0,83 | 1,67 | 2,51 | 3,37 | 4,22 | 5,10 | 5,99 | 6,88 | 7,77 | 8,68 | 9,60 | 10,53 |
| 170 | 0,85 | 1,72 | 2,58 | 3,47 | 4,35 | 5,25 | 6,17 | 7,09 | 8,01 | 8,94 | 9,89 | 10,85 |
| 175 | 0,88 | 1,77 | 2,66 | 3,57 | 4,48 | 5,41 | 6,35 | 7,30 | 8,24 | 9,21 | 10,19 | 11,17 |
| 180 | 0,90 | 1,82 | 2,74 | 3,67 | 4,61 | 5,56 | 6,53 | 7,51 | 8,48 | 9,47 | 10,48 | 11,48 |
| 185 | 0,93 | 1,87 | 2,81 | 3,77 | 4,74 | 5,72 | 6,72 | 7,71 | 8,71 | 9,73 | 10,77 | 11,80 |
| 190 | 0,95 | 1,92 | 2,89 | 3,88 | 4,86 | 5,87 | 6,90 | 7,92 | 8,95 | 9,99 | 11,06 | 12,12 |
| 195 | 0,98 | 1,97 | 2,96 | 3,98 | 4,99 | 6,03 | 7,08 | 8,13 | 9,18 | 10,26 | 11,35 | 12,44 |
| 200 | 1,00 | 2,02 | 3,04 | 4,08 | 5,12 | 6,18 | 7,26 | 8,34 | 9,42 | 10,52 | 11,64 | 12,76 |

NOTES :