TubeInspect
&
BendingStudio XT

Technical Data Sheet

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Content

1 The optical tube measuring system TubeInspect

1.1 Introduction

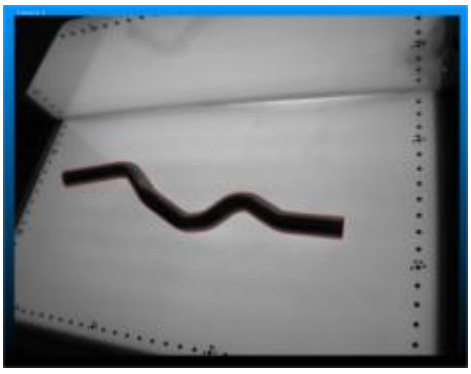
The **TubeInspect** tube measuring system offers trend-setting technology for the highly precise measurement of tubes, wires and other components with tube-like geometries such as branched tubes. Since **TubeInspect** was originally only designed for measuring curved tubes all these components have been summarized below under the main term “tube” for the sake of simplicity. TubeInspect offers possibilities for the optical measurement of tubes, for determining setup and correction data through to quality assurance during production. **TubeInspect** is capable of replacing mechanical gages. TubeInspect can significantly shorten setup times for new bending programs on the bending machine.
The most precise measuring results can be achieved without moving the tubes or the camera using high-resolution stationary digital cameras. This means that the tubes can be measured without using special clamping or aligning devices.
TubeInspect gives you the necessary flexibility in tube manufacturing quality assurance. Protracted setup times when converting production to new parts or part variants are no longer necessary: **TubeInspect** is ready for use immediately after initialization of the digital nominal data. If corrections arise from the measured tube, **TubeInspect** can communicate the improvements to the bending machine which are then transmitted directly to the CNC program.

TubeInspect stands for efficient quality assurance in tube manufacturing and can be deployed

- as an optical tube measuring system and programmable optical gage,
- for setting up and correcting bending programs,
- for reverse engineering of sample tubes and initial sample testing and also
- for automatic 100% testing in a robot manufacturing cell.

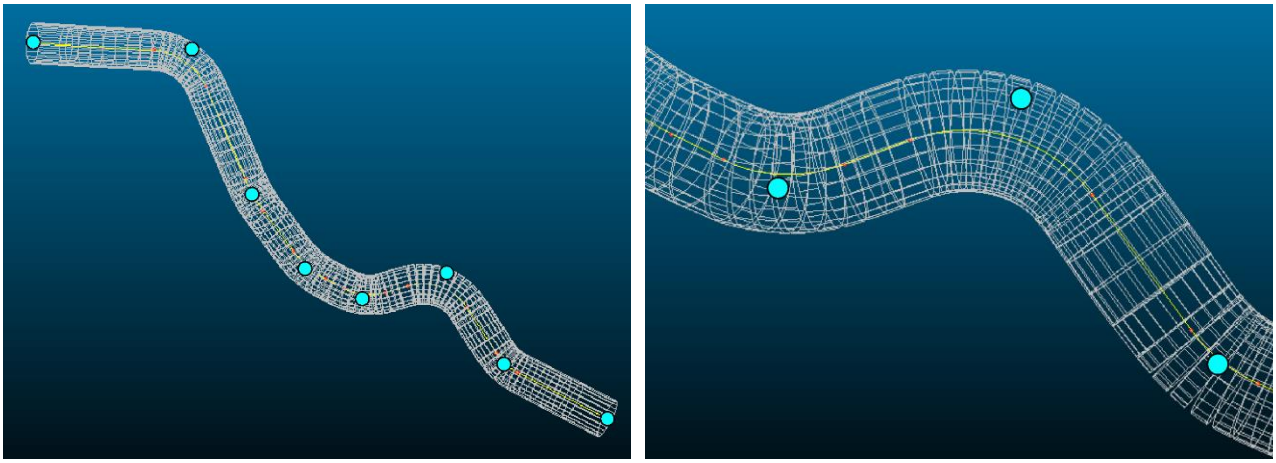
1.2 Functional principle

TubeInspect records tube geometry contact-free within a few seconds with the assistance of high-resolution digital cameras. The tube to be measured is first placed in the measuring cell. The insert position is unimportant and no special equipment as e.g. tube holder is required. Under certain circumstances, visibility may be impaired with complex-shaped tubes. Preferred positions, in which all areas of the tube are ideally visible, can be defined in the measuring software and used as a reference position for future measurements to correct this. Several high-resolution digital cameras record the tube geometry from different angles. In the measurement images, the tubes are shown as silhouettes against a backlit measuring surface and the contours are then measured with sub-pixel precision. This makes it possible to reliably measure tubes of different materials, colors and surfaces. Preparation of the surface may be necessary only with transparent or extremely reflective surfaces.

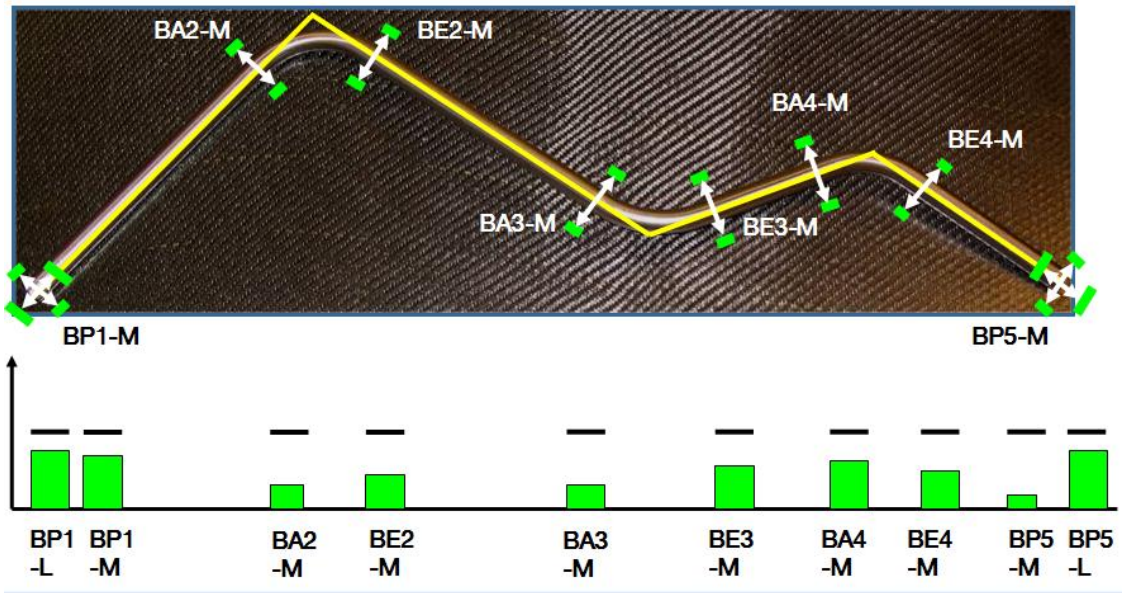


The cameras are triggered synchronously. Nevertheless, operator should avoid any motion blur effects due to moved or post-oscillating tubes. The pictures are transferred to the computer’s RAM for further processing in

a fraction of a second. The component can then already be removed from the measuring area. The contours measured in the individual pictures are then assembled into a complete three-dimensional finite cylindrical model of the tube by means of photogrammetric calculations. Thereby the algorithm is laid out for round tube and wire cross sections. With the release of BendingStudio XT, the measurable spectrum is extended to profiles with rectangular cross-sections. The primary measurement result is the centerline of an arbitrarily bent tube which is displayed as a spatial polygon with adjustable point distances.



This forms the basis for all further analyses such as determination of the bending elements, calculation of the X, Y and Z coordinates of the bending points or the comparison with a nominal geometry stored in the tube database. Multiple measurements are possible which are automatically consolidated into an overall result by the system to optimize measurement precision and to measure very long or complex tubes in multiple steps.
TubeInspect is designed as an optical gage and brings together the properties of a co-ordinate measuring system and a mechanical gage. When compared to nominal data, the measured centerline's deviation from the nominal data is displayed directly.



Standard tube geometries (classical bend tubes) usually consist of straight and bent segments and are described by means of bending points and bending data. This data is, however, only of limited suitability as derived measurement results for assessing the quality of tube geometries. Deviations in bending data can either cancel each other out or become more pronounced due to leverage. Bending points sometimes lie far outside the actual tube. The slightest deviation in the tube can already lead to a large dispersion of the bending

point's coordinates at this stage. **TubeInspect** calculates the so-called outer sheath deviation; this is the deviation at the bend start and end points, sometimes also called tangent points, vertical to the nominal tube. This approach is also recommended in various directives such as the American SAE J2551. All specifications regarding measurement precision therefore subsequently refer to the sheath deviation.

Apart from the blinds and flaps, **TubeInspect** has no moving parts and is therefore low maintenance. There are evenly spaced reference markings on the measuring field for the spatial orientation of the cameras. These points effectively represent the calibration standard of the measuring cell and are calibrated with high precision and traceability by Hexagon during construction of the system. Although any change in the markings is virtually impossible due to the use of glass references regular monitoring and recertification, is recommended. Changes in the camera positions are monitored during operation by means of the reference markings and thus permit self-monitoring of the system.

The most important characteristics of TubeInspect are summarized below:

- As a programmable optical measuring system, **TubeInspect** can replace cost-intensive gages. The test criteria of a mechanical gage can be represented today with **TubeInspect** through the measurement of the sheath deviation based on a tolerance sleeve curve. The result graph is easy to understand and structured in the style of the classic gage test. In addition, the inspection plans could be extended by the use of functional dimensions which represents the specific tolerances for distance and angle of the drawings.
- The tube to be measured is placed in the optical measuring cell without using special clamping or fixture devices.
- Deflection due to the self-weight of thin or elastic workpieces is compensated by the automatic deflection correction in the measuring software.
- A measurement takes just approximately 2 – 30 seconds depending on the tube length and the number of bends.
- The actual measured contour is matched with the tube nominal data which is stored on the measuring computer with the measuring program in a database.
- TubeInspect supplies user-independent and repeatable results and thus fulfills the demanding measuring tool capability requirements and proof of suitability of test processes.
- Data reports can be printed out or stored in multiple languages; this means that a quality certificate for the measured tube is available. Serial measuring files can be produced as an option which can be exported to statistics programs. An Interface to qs-STAT is already part of all BendingStudio packages. Further interfaces can be supplied on request.
- TubeInspect can be directly connected to modern CNC bending machines to communicate corrections online. This results in a significant shortening of setting-up processes and downtimes in the manufacturing environment. All BendingStudio packages have an open bending machine for correcting standard tube geometries. Almost all common bending machines can be connected.
  NOTE: Bending machine must be enabled for import of correction data.
- Prototyping tubes could be captured and measured with a reverse engineering function. These generated bending data can be used for set-up of benders or for postprocessing with a CAD-system.

1.3 TubeInspect Models

Hexagon is manufacturing tube measurement system incl. measurement software since more than two decades. The most important launches and milestones are:

HARDWARE

- 1994-2004 First optical tube measurement system OLM
- 2004-2014 TubeInspect (full-size), TubeInspect S, TubeInspect HS, TubeInspect HD
- 2014-2020 TubeInspect P8, TubeInspect P16
- 2020- TubeInspect P8.2, P16.2, P8.2HRC, P16.2 HRC, AUTOMATION

SOFTWARE

- 2012 BendingStudio software
- 2021- BendingStudioXT software

2 Measurable tube spectrum

The following tube spectrum can be measured with **TubeInspect**:

2.1 Tube diameter

Measurement range for outer diameter with:

- TubeInspect P8.2: 2 mm to 125 mm
- TubeInspect P8.2 HRC: 0.8 mm to 125 mm
- TubeInspect P16.2: 3 mm to 200 mm
- TubeInspect P16.2 HRC: 1.5 mm to 125 mm

2.2 Tube length

See measurement volume. Longer tubes can be measured in several sections if necessary. The maximum measurable end-to-end length also depends on the tube geometry. The recommended maximum end-to-end length is:

- TubeInspect P16.2: 7.000 mm
- TubeInspect P8.2: 1.500 mm
- TubeInspect P16.2 HRC: 7.000 mm
- TubeInspect P8.2 HRC: 1.500 mm

2.3 Tube geometries, bending angles, pushes

- Standard tube geometries consisting of straight and bended segments
- Bending angle of 1° to <340
- Geometries without pushes, so-called bend-in-bend shapes
- Geometries with changing bend radii (free-formed tubes)
- Any shapes without calculation of bending data

2.4 Free-form bent tubes with continuously changing radii

It is possible to measure a centerline of a freeform bended tube. The evaluation software offers different possibilities of calculation and can generate a freeform bending program constructed of a measured master tube or an imported centerline.

2.5 Fixings and additional features

The position and alignment of fixings, flanges and attachments can be measured with the assistance of TubeInspect adapters as long as visibility is available. Furthermore, with BendingStudio version 7.0 and higher it is possible to measure position fixings, flanges and attachments without mounting adapters directly from the TubeInspect images. This function is named “CAD ADAPTER” (see and is available only for high-resolution models TubeInspect 8.2 HRC and P16.2 HRC.

2.6 Measurement of assemblies

Tube segments of assemblies, for example as be present in exhaust systems, can also be measured. At least one bend is required on each individual tube.

2.7 Flexible tubes/hoses

It is also possible to measure preformed hoses, tube-hose combinations, tube-preformed hose combinations and flexible tubes. BendingStudio offers different options to evaluate such measurements.

2.8 Materials

All materials and surfaces can be measured. Only parts made of transparent materials such as glass cannot be measured without spray.

2.9 Limitations

Due to the almost arbitrarily large variety of tube deformations and the many different measuring tasks it cannot be ruled out that tube geometries can only be measured partly or with lower precision.

3 Rectangular profiles

With the release of BendingStudioXT, the measurable tube spectrum is extended from round tubes/wires to profiles with square or rectangular cross-sections.
The profile cross-section can have rectangular or rounded edges. Bends are only possible over side faces of the profile. On the hardware side, the TubeInspect P series is recommended for measuring rectangular profiles due to the higher camera resolution.

With regards to materials and dimensions, the measurable profile range corresponds to the measurable tube range with the following restrictions:

3.1 Profile diameter / cross-section diagonal

- TubeInspect P8.2: 8 mm to 125 mm
- TubeInspect P8.2 HRC: 2 mm to 125 mm
- TubeInspect P16.2: 12 mm to 200 mm
- TubeInspect P16.2 HRC: 8 mm to 200 mm

3.2 Profile length

See measurement volume. Longer tubes can be measured in several sections if necessary. The maximum measurable end-to-end length also depends on the tube geometry. The recommended maximum end-to-end length is:

- TubeInspect P8.2: 1.500 mm
- TubeInspect P8.2 HRC: 1.500 mm
- TubeInspect P16.2: 7.000 mm
- TubeInspect P16.2 HRC: 7.000 mm

3.3 Tube geometries, bending angles, pushes

- Standard tube geometries consisting of straight and bended segments
- Bending angle of 1° to <340
- Bends are only possible over the side surfaces of the profile
- Geometries without pushes, so-called bend-in-bend shapes
- Geometries with changing bend radii (free-formed tubes)
- Random shapes without calculation of bending data

3.4 Freeform bent profiles with continuously changing radii

It is possible to measure a centerline of a freeform bended tube. The evaluation software offers different possibilities of calculation and can generate a freeform bending program constructed of a measured master tube or an imported centerline.

3.5 Torsion

Torsion determination is possible for standard bending geometries and free-form geometries. For standard bending geometries, the torsion may only be present on straight segments. For measurement with TubeIspect, the aspect ratio must be at least $1:\sqrt{2}$.

3.6 Fixings and additional features

The measurement of holders and attachments is currently not possible for rectangular profiles.

3.7 Measurement of assemblies

The measurement of assembly parts is currently not possible for rectangular profiles.

3.8 Flexible tubes/hoses

The measurement of tube-hose combinations, flexible profiles, etc. is currently not possible.

3.9 Overview of BendingStudio features that are currently not supported for rectangular profile measurement

- Diameter change
- Bevel cut
- Rotated symmetrical formed ends
- TubeInspect Adapter
- CAD-Adapter
- Tube-Hose-Combination
- Straight on and elbow adapters
- Length measurement
- Straightness measurement
- Ovality
- Branch
- Build module
- Deflection compensation

For more detailed explanations of individual features, see section 0.

3.10 Materials

All materials and surfaces can be measured. Only parts made of transparent materials such as glass cannot be measured without spray.

3.11 Limitations

Due to the almost arbitrarily large variety of profiles deformations and the many different measuring tasks it cannot be ruled out that tube geometries can only be measured partly or with lower precision.

4 TubeInspect adapters - hardware

The alignment of ends, brackets and additional features, the logging and measurement of which is not possible for the **BendingStudio** software without auxiliary material, can be measured by using the **TubeInspect** adapters.
At present, the following TubeInspect measurement adapters are deliverable:

Connection adapter 20-50	Magnetic holder, used as connection adapter and to measure hidden straights, tube diameter 20-50 mm
Connection adapter 4-20	Quick clamp, used as connection adapter and to measure hidden straights, tube diameter 4-20 mm
7-point position and axis adapter 5-14	For through holes, diameter 5-14 mm, self-centering fixation, M4 thread to connect individual mounts
7-point position and axis adapter 5-19	for 5-19 mm boreholes/orifices, self-centering locating element, M4 thread for fastening individual connections
7-point individual adapter	M4 thread to connect individual mounts
7-point end adapter D50	Self-centering chuck D50, 3 collets, for diameters 10-72 mm
7-point end adapter D80	Self-centering chuck D80, 3 collets, for diameters 50-110 mm
7-point end adapter D125	Self-centering chuck D125, 3 collets, for diameters 100-170 mm
Elbow adapter 4.75-10i	Tube Diameter 4,75 mm, inside thread M10x1
Elbow adapter 4.75-10a	Tube Diameter 4,75 mm, outside thread M10x1
Elbow adapter 4.75-12a	Tube Diameter 4,75 mm, outside thread M12x1
Adapter for Stabilizer (only set with 4 adapters available)	2 pc. adapter cube self-centering for ø 8- 14mm; 2 pc. adapter cube with mechanical stop and self-centering for ø 8- 14mm, transportation box

5 BendingStudio XT – Software packages

5.1 Software packages and options

As the leading platform for tube and wire analysis, BendingStudio offers a high level of functionality with various software modules. There are three packages to choose from, adapted to the respective requirements: STANDARD, PREMIUM and AUTOMATIC. The included functions are summarized in the following table.

Functionalities	**BendingStudio XT Packages** incl. 12 months SMA ■ = functionality included □ = functionality not included ○ = functionality as option	STANDARD	PREMIUM	AUTOMATIC
MEASUREMENT SYSTEMS	• TubeInspect (-, S, HS, HD) • TubeInspect P8 and P16 • TubeInspect P8.2 and P16.2 • TubeInspect P8.2 HRC and P16.2 HRC • Absolute Arm with TubeProbe (RDS) • Absolute Arm with AS1/RS6 Scanner	■ ■ ■ ■ ■ ■	■ ■ ■ ■ ■ ■	□ □ □ ■ □ □
BASIC FUNCTIONS	Part database; user management; settings for display levels; measurement of tubes and wires or parts with multiple diameters, rotationally symmetric formed tube ends; calculation of bending data (LRA/PBR, XYZ, radius); nominal-to-actual comparison; tolerance envelope inspection (optical gauge); functional dimensions; reverse engineering; measurement jobs; flexible configurable measurement report	■	■	■
MEASURING TOOLS	Straight-on and elbow adaptors; TubeInspect adaptors	■	■	□
DEFLECTION COMPENSATION	Deflection correction for elastic tubes caused by gravity (e.g. long thin tubes or rubber tubes), material data base, not applicable for free-formed tubes	■	■	■
BRANCH	Measurement of branched tube geometries, allows testing of both the individual tubes and the assembled part, function requires at least one bend for each individual tube, only applicable for cylindrical cross sections	○	■	■
CAD-WIZARD	IMPORT and EXPORT of IGES and STEP files, only for parts with circular cross-sections, import by automatic or interactive selection of straight and bended segments of tube components, calculation of bending elements (XYZ/LRA) to prepare a bending program, export of tube geometry in IGES and STEP format	○	■	■
BEVEL CUT	Functionalities for measurement of bevel cut ends	□	■	■
CAD-ADAPTER	Measurement function to determine position and direction of e.g. mounted holders or attachments, evaluation is done by analyzing image or scan data and comparison with reference generated from CAD data	□	○[1)]	■
DIAMETER CHANGES	Measures positions of diameter changes along the tube	□	■[2)]	□
PROFILE	Measurement for classic and free-formed bent parts with rectangular and oval cross-sections, includes calculation of bending data	□	○[2)]	■
Bender interface STANDARD	Calculation of bending correction data; virtual gauge simulation tool; open bender interface. Note: uploading of correction data must be enabled on the bending machine	■	■	■
Bender interface FREEFORM	Calculation of bending correction data including bending radii; virtual gauge simulation tool; open bender interface. Note: uploading of correction data must be enabled on the bending machine	□	■	□

[1)] Function only available when using Absolute Arm with AS1/RS6 scanner or TubeInspect HRC models.
[2)] Function only available when using Absolute Arm with scanner or TubeInspect models.

OPTIONS for BendingStudio XT STANDARD	
BRANCH *ART130696*	Measurement of branched tube geometries, allows testing of both the individual tubes and the assembled part, function requires at least one bend for each individual tube, only applicable for cylindrical cross sections
CAD WIZARD *ART106484*	IMPORT and EXPORT of IGES and STEP files, for parts with circular cross-sections, import by automatic or interactive selection of straight and bended segments of tube components, calculation of bending elements (XYZ/LRA) to prepare a bending program, export of tube geometry in IGES and STEP format

OPTIONEN für BendingStudio XT PREMIUM	
CAD ADAPTER [1)]	Messfunktion zur Bestimmung von Position und Richtung z.B. montierter Halter oder Anbauteile, Auswertung erfolgt mittels Analyse von Bild- oder Scandaten und Vergleich mit aus CAD Daten ermittelter Referenz
PROFILE [2)]	Messung für klassische und freiformgebogene Bauteilen mit rechteckigem und ovalem Querschnitt wie z.B. Stromschienen oder Hairpins, einschließlich Berechnung von Biegedaten

OPTIONEN für BendingStudio XT STANDARD, PREMIUM and AUTOMATION	
OFFLINE	Lizenz für Offline Datenbearbeitung ohne Messsystem, USB Dongle, auch anwendbar für Erweiterung der Offline Floating Lizenz (ART111396) um einen weiteren Nutzer
FLOATING LIZENZ	Lizenz für Offline Datenbearbeitung ohne Messsystem, Netzwerklizenz für einen Nutzer, USB Dongle
DATA BASE SERVER	Vereinfachte BendingStudio Lizenz für die Verwaltung der BendingStudio Teiledatenbank auf einem separaten Server / Rechner, USB Dongle HINWEIS: nur lauffähig bei entsprechender kundenseitiger Netzwerkkonfiguration

[1)] Function only available when using Absolute Arm with AS1/RS6 scanner or TubeInspect HRC models.
[2)] Function only available when using Absolute Arm with scanner or TubeInspect models.

5.2 Overview of file formats for import/export

File Formats, Bending machines	
Data import formats	G-Tube (GTT), TubeShaper (TSP), Vector (PRT), CSV, FIF, SV, VDA, XML, $$$; other ASC II formats individually configurable – it is possible to import multiple files in one batch
Data export formats	CSV, FIF, SV and other ASC II formats individually configurable, DFQ (qs-STAT)

6 AUTOMATION

The AUTOMATION software package presented in Section 5.1 enables the integration of TubeInspect into an automated production cell. For this purpose, BendingStudio XT provides two possibilities of communication between measuring system, controller and robot: a file-based XML interface and a PLC module.

Note:

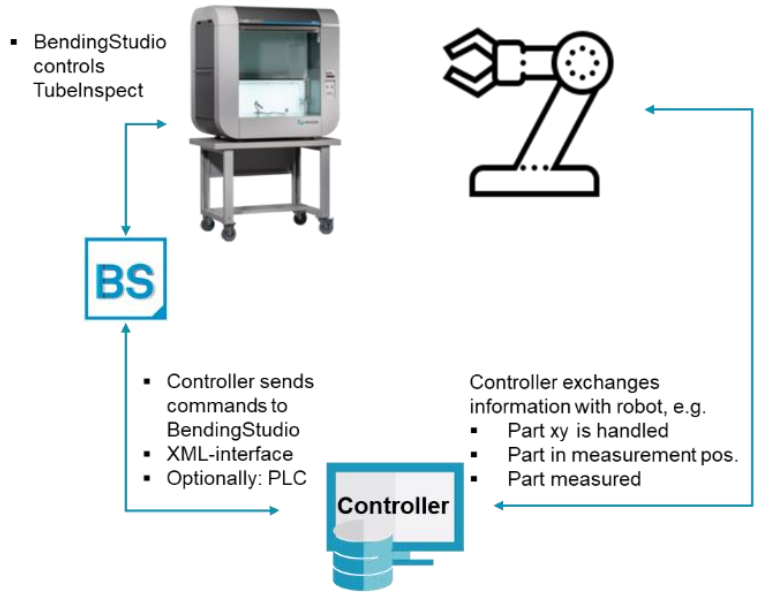
- automation is only possible with the models TubeInspect P8.2 HRC and TubeInspect P16.2 HRC
- the possibility to measure TubeInspect adapters (section 4) is not provided for automation (mounting of adapters cannot be automated)
- the function for measuring tube-hose combinations is not available for automation (interactive measurement for stretching the tube portion cannot be automated)

The time required for the measurement of the components depends on their complexity. To optimize the cycle time, it is possible to remove the components from the measuring area after the image acquisition by TubeInspect. It is generally recommended to have the measurability of components in an automated production cell checked with Hexagon or an authorized partner.

6.1 XML interface, remote control

BendingStudio AUTOMATION provides the possibility to remotely control the software based on a da-teibased XML interface.

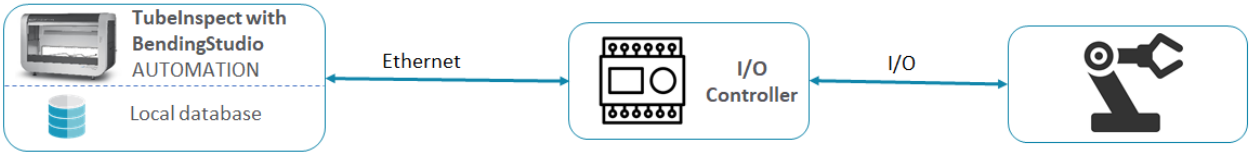
The interface is provided when the BendingStudio Automation App is started. The connection is made via a defined port number. BendingStudio waits for queries or commands and acknowledges each query/command by sending a response. A test tool for sending commands is available.



6.2 PLC interface

With the BendingStudio PLC Automation Kit (ART130586), a direct connection between TubeInspect and robot can be established without the need for software programming for the interface. The kit consists of a PLC (programmable logic controller) with digital inputs and outputs based on RevPi technology and is equipped with a special BendingStudio PLC firmware.

The PLC is configured via a web interface. In this, the pin assignment for the components intended for automation can be made and pins for calibration, measurement start, etc. can be defined.



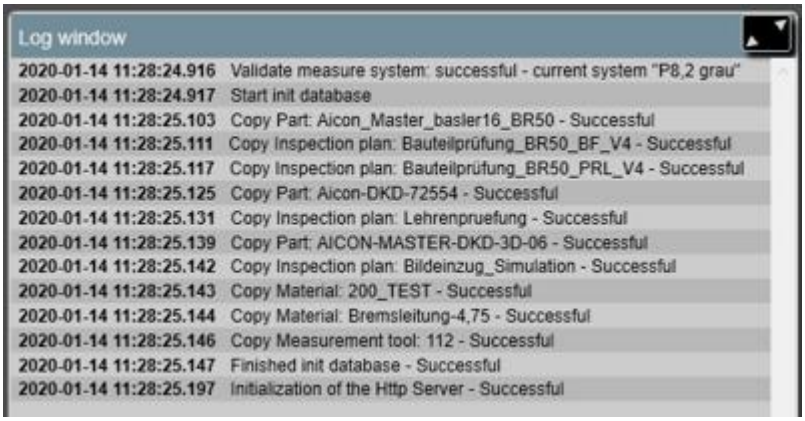
6.3 Workflow automation

The workflow for preparing parts for automation measurement can be summarized as follows:

- **Step1: Selection for automation**
  - Check whether the test plan stored in BendingStudio is suitable for automation. (Test plans that require the use of measuring aids or that take tube/hose combinations into account are not suitable for the reasons mentioned above).
  - After the test, the test plan is marked "SELECTED FOR AUTOMATION". Optionally, component or materials are provided with a write protection.

- **Step2: Setting further parameters**
  - As with manual operation, further parameters can be selected in BendingStudio, e.g. for system calibration, selection of storage locations and for log generation.

- **Step3: Initialization**
  - After all preparations have been made, the operator initializes the automation.



- **Step4: Automation**
  - The controller responsible for process control now has access to the BendingStudio functionality and can control the software remotely via the commands of the XML interface or via the PLC

7 Connection to Bending machines

7.1 Introduction

In a production environment, bending machines must be repeatedly aligned anew, e.g., for a change of production or because individual charges of material differ. With the software modules Interface Bending Machine STANDARD or Interface Bending Machine Freeform, **BendingStudio XT** can considerably support and thus shorten the setup of a bending machine thanks to the determined correction values. The savings potential gained in this way is enormous.
The interface is based on an open interface description available to all bending manufacturers, free of charge. In the meantime, many manufacturers support the possibility of transferring correction data determined with **BendingStudio XT** into the CNC program of their bending machine. The software allows the transfer of correction data to up to 100 simultaneously connected bending machines.
Note: File import of the BendingStudio XT correction file into the respective CNC control program of the bending machines is **not** included in the scope of delivery and is to be enquired into with the bending machine manufacturer.

7.2 General information about interfaces of bending machines

- BendingStudio can use several types of communication (« Protocols ») to send to benders and receive data from benders. BendingStudio offers a wide range of different formats based on a more than 20 years' experience on this field. A quite popular interface today is SV Network. Nevertheless, other types are working properly also and are usually dedicated to specific types of benders.

- BendingStudio bending machine interface is compatible with machines of most known bender makers. Nevertheless, a successful connection to a single bender requires, that this **bending machine is enabled to upload correction data**. Usually, all benders once connected to any measurement system, can be connected to BendingStudio also.

- SV Network is widely used by the tube production. Even today more and more bender makers use this interface as their standard and therefore it is compatible with a wide range of benders. SV Network is supported by BendingStudio.

- Most BendingStudio bending machine interfaces are based on file exchange with the bending machine. This means, that BendingStudio exports a data file (e.g. nominal data, correction data) in text format (ASCII format) which will be loaded up to the bender. Communication with tube benders can be uni-directional (meaning that the bender can only receive data from BendingStudio) or they can be bi-directional. In this case the bender receives and sends data.

- BendingStudio bending machine interface on customer site will be configurated during installation to his machines and his workflow. After configuration BendingStudio operates the different formats automatically by selecting the bender in the software.

- Usually, the data transfer is set up via the TCP/IP protocol of a local network or an existing company network. If no network is available, the correction values can also be transferred between the bending machine and the BendigStudio PC via a data carrier (e.g. USB memory stick).

- Especially with older bending machines, the communication of the tube measuring device with a bending machine can be a technical challenge. A serial interface (e.g. RS-232) is often used. Serial interfaces between the bending machine and the measuring device usually have to be configured and programmed individually, since e.g. transmission protocols and rates have to be coordinated. Hexagon will be pleased to advise you on the connection of your bending machines.

7.3 Cooperation with bending machine manufacturers

List of bending machine manufacturers whose bending machines can be connected to BendingStudio XT:

Brand	Model	Controller / Soft-ware	Year	Communication Protocol	Uni/ Bi
Addison McKee (to-day ADD-EATON by Numalliance)	EB80	Twin CAT NC PTP V2.11.1553	Since Oct 2016 *(bender software must be updated)*	SV Network	⇄
	All	Mark IV / Mark V	Since 2001	SV NetLog	⇄
	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	⇄
AIM	AFM 3DX AFE 3DX AFC 3DX		Since 2016	SV Network	⇄
AMOB	CH-L and CH-HD Series	Omron Sysmac J2M	Since 2015	SV Network	⇄
BLM	All		< 2011	BLM file INTERSCA	⇄
	All	VGP3D v111110 *(v180605 needed for 180°bends)*	Since 2011	SV NetLog	⇄
	All	VGP3D v130731	Since 2013	SVNetwork ($$$ import)	→
	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	⇄
COMCO	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	⇄
Chiyoda	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	⇄
	ALL		< 2013	Chiyoda format	→
Crippa	ALL	UII	Since 2015	SV Network	⇄
	ALL		< 2015	Crippa formats	⇄
CSM	ALL		Since 2012	SV Network	⇄
	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	⇄

Eagle	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	
Eaton Leonard	All	VE-LOG	80's	*Customized solution*	
	All	EL-2000	Mid 80's - Early 90's	*Customized solution*	
	All	Premier	Early 90's – 2014	*Customized solution*	
	All	LightSpeed *(for benders with a SERIAL connection port)*	Since 2002	*Customized solution*	
	All	LightSpeed V1.1.4	Since 2002	SV Network	
	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	
Herber	All	Herber HMI	Prior to 2017	BendingStudio korrekt.mes	
	All	Herber HMI2018	Since Oct. 2017	SV Network	
GSIE	All	GSIE Format	Since 2020	Customized text file	
Horn Machine Tools (HMT)	All	BendPro G2 V2 (please check that communication is allowed)	Since 2015	SV Network	
IKM / King Mazon	CNC Pipe Bender	King-Mazon CNC 2017 v7.0	Since 2017	SV Network	
Keins	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	
Mewag	All	MTC-XP V2.2	Since 2003	BendingStudio korrekt.mes	
Miic	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	
NISSIN	All			NISSIN file	
Numalli-ance	All	Touch&Form	-	BendingStudio korrekt.mes	
Pedrazzoli	All		Since 2017	SV Network	
Pines	All	TS-2000 Workstation 4.1.0.7	Since 2002	SV Network	
	Retrofitted	Current Tech Controller	Since 2013	SV Network	

		BendPro G2 V2 (please check that communication is allowed)			
Silfax	-	PCU50.3 / STUB v2.4	Min 2003	Silfax - STub format	
SOCO	All	IPC control / I 2 software	Since 2005	SV Network	
	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	
Schwarze Robitec	All			SR Tube	
	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	
Star	TREX 1200	B&R Controller *(USB or LAN connection)*	Since 2016	SV Network	
	All	ISO V 3.5.2	Since 2016	SV Network	
Transfluid	All	"Tproject" V3.39 *simulation software must have 'SV Network' option.*	Since 2017 *(2014 – 2016 check for upgrade)*	SV Network	
	All			Transfluid format	
UTE			Since 2020		
Wafios	BMZ & RBV	WPS 3.0 V5.0.3.0 WPS 3.2 EasyWay *(iQinspect option)*	Since 2006	BendingStudio korrekt.mes	
YLM	CNC90MS-LAE CNC90MS-RAE CNC90MSLSM-7A CNC90MSLOSM-7A CNC90MS-ROSM-6A CNC131MSRAE-11A CNC131MSLAE-11A		Since 2016	SV Network	
	Retrofitted	Current Tech Controller BendPro G2 V2 (please check that communication is allowed)	Since 2013	SV Network	

Note: File import of the TubeInspect correction file into the respective CNC control program of the bending machines is **not** included in the scope of delivery and is to be enquired into with the bending machine manufacturer.

8 Measurement time, measurement accuracy and acceptance

8.1 Measurement time

TubeInspect makes possible the measurement of bent tubes within seconds. The duration of the measurement is dependent in this regard on the length of the tubes and the number of bending points. Typical measurement times only for tubes without features and fittings are, e.g.:

Hydraulic tube,	5 bending points,	500 mm tube length:	measurement time ca. 2-3 seconds
Exhaust tube,	7 bending points,	2000 mm tube length:	measurement time ca. 10 seconds
Brake tube,	15 bending points,	1500 mm tube length:	measurement time ca. 15 seconds
Brake tube,	40 bending points,	2500 mm tube length:	measurement time ca. 30 seconds

The measuring time here is defined as the duration from the start of the measurement to the result of the sheath tolerance check for a single measurement. For measurements with CAD adapter function, depending on the complexity of the components and CAD design, a measuring time of approx. 10 - 60 seconds per CAD adapter must be calculated. Handling times are not considered. In addition, optional further calculations can change the measuring time.

8.2 Measurement accuracy

Hexagon specifies the following measurement accuracy for the **TubeInspect** tube measurement system:

Measurement system	Measurement Accuracy	Specification
TubeInspect P16.2	0.085 mm	1 σ sheath deviation [1)]
TubeInspect P16.2 HRC	0.085 mm	1 σ sheath deviation [1)]
TubeInspect P8.2	0.035mm	1 σ sheath deviation [1)]
TubeInspect P8.2 HRC	0.035mm	1 σ sheath deviation [1)]

[1)] The indicated measurement accuracy (1σ = 1 sigma) is applicable for the measurement of ideal tubes comprising geometrically sound straight and bend segments.

8.3 Measuring capability (Procedure 1)

This procedure analyzes the accuracy and repeatability of a measuring system. Utilized for the test is a measurement reference tube with a known characteristic value. The measurement standard is measured 50 times (at least 25 times) and thereby removed before each measurement and again replaced. Based on the tolerance to be later checked by the system, the standard deviation of the measured value and the systematic error of measurement, the indices C_g and C_{gk} are then calculated.
The measurement accuracy specified by Hexagon (1 sigma sheath error) is verified by Hexagon by means of a measuring system analysis study in accordance with TubeInspect procedure (cf. Ch. 8.5).

8.4 Gage R&R (Procedure 2)

This procedure tests the repeatability and reproducibility of a measuring system (also simply *R&R or Gage R&R*), and is not implemented until the measuring system has been classified as capable pursuant to Procedure 1. In this regard, ten pieces are measured two or three times by two or three different operators.
A Gage R&R test is done with customer parts and is therefore **not** included in the scope of delivery.

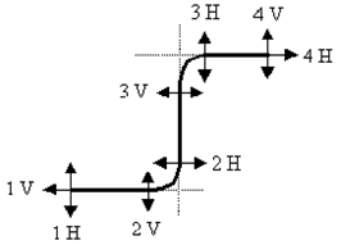
8.5 Acceptance test, proof of measuring accuracy

In the course of an initial installation or a certification, Hexagon verifies the specified measuring accuracy with a measuring system analysis (Procedure 1).

For calculating the C_g and C_{gk} indices, the following TubeInspect calculation procedure is implemented:

$$Sm = \sqrt{\frac{\sum_{i=1}^{N} \left(Xim - \overline{X}m\right)^2}{N-1}} \qquad \overline{X}m = \frac{1}{N}\sum_{i=1}^{N} Xim$$

$$Cgm = \frac{Tm - \overline{X}m}{3 * Sm} \qquad Cgtqtube = Min\left[Cgm\right]_{m=1}^{M}$$



m=1...M	measurements	Sm	Standard Deviation
Tm	Sheath Tolerance	Cgm	Capability Index per point
$\overline{X}m$	mean value	Cg TQtube	Capability Index TQtube

TubeInspect P16.2, P16.2 HRC: Verification of the specified measuring accuracy is considered fulfilled when the Cgk value ≥ 1.33 for the sheath tolerance characteristic at a tolerance of T = 0.85 mm has been obtained with the TubeInspect Master Tube.

TubeInspect P8.2, P8.2 HRC: Verification of the specified measuring accuracy is considered fulfilled when the Cgk value ≥ 1.33 for the sheath tolerance characteristic at a tolerance of T = 0.35 mm has been obtained with the TubeInspect Master Tube

9 Maintenance

9.1 Introduction

Thanks to the optical measuring principle, past experience has shown the **TubeInspect** tube measuring system to be particularly low-maintenance. Proper maintenance of the hard- and software components is nonetheless necessary for the continuous and reliable functioning of the measuring system and for maintaining the value of the investment over a long period of time.

9.2 Hardware maintenance and recertification

The new P-series fulfills highest requirements regarding accuracy and speed. The long-life and low-maintenance LED technology guarantees a particularly smooth illumination of the measuring field, and enables an even more reliable measurement of tubes and wires of all materials. Complex bends are captured even more detailed which improves the repeat accuracy. The measuring field was further optimized: the panel of the reference field is now supplemented with additional glass elements as beams for the low-maintenance reference points, which do not have their own power supply and are more precisely measurable. That is why TubeInspect P8|P16 works reliable and accurate over a long period without any manufacturer maintenance.

For a field check of the specified measurement accuracy customer may use Hexagon's certified master tube. Hexagon offers a calibration service for this tube.

On request Hexagon or by Hexagon authorized person/dealer serves a full system checkup and recertification on site and provides all necessary calibration tools. In this case a complete hardware check is included, too.

A system verification is generally required by the customer's quality assurance department.

9.3 Software update and maintenance agreement

Customers with a valid software update and maintenance agreement receive free software updates for their purchased software modules. Furthermore, the agreement offers a number of benefits: Hexagon Support serves you in case of questions or measurement problems by phone, e-mail or an internet-based support tool (e.g. GoTo-Meeting) for immediate trouble shooting.

At your request, the software update and maintenance agreement will include a dongle insurance against loss. For this, the dongle will be enabled only for a limited period (e.g. 12 months). In case of loss, a replacement dongle can be purchased only for the hardware costs of the dongle itself (app. 250 €).

Note: Please understand that without a software maintenance and support agreement Hexagon can only provide very limited support.

9.4 Remote maintenance

Hexagon offers for TubeInspect a remote maintenance via an internet based communication tool (e.g. GoToMeeting) will be used to login on the machine. This requires internet access for the TubeInspect controller.

For an off-line support TubeInspect offers to save a complete set of images including the relevant project data. All files can be transferred to Hexagon by e-mail, data carrier or FTP up / download for the detailed analysis by our Hexagon Support Team. BendingStudio offers a one button function to create automatically a complete data set for support issues.