Kelvin Tool Changer

User Manual

Version: 1.2

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Automatic tool changer for small collaborative robots

Original Instructions (en)

CE marking and user manual are made in cooperation with Maskinsikkerhed ApS

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1 Preface

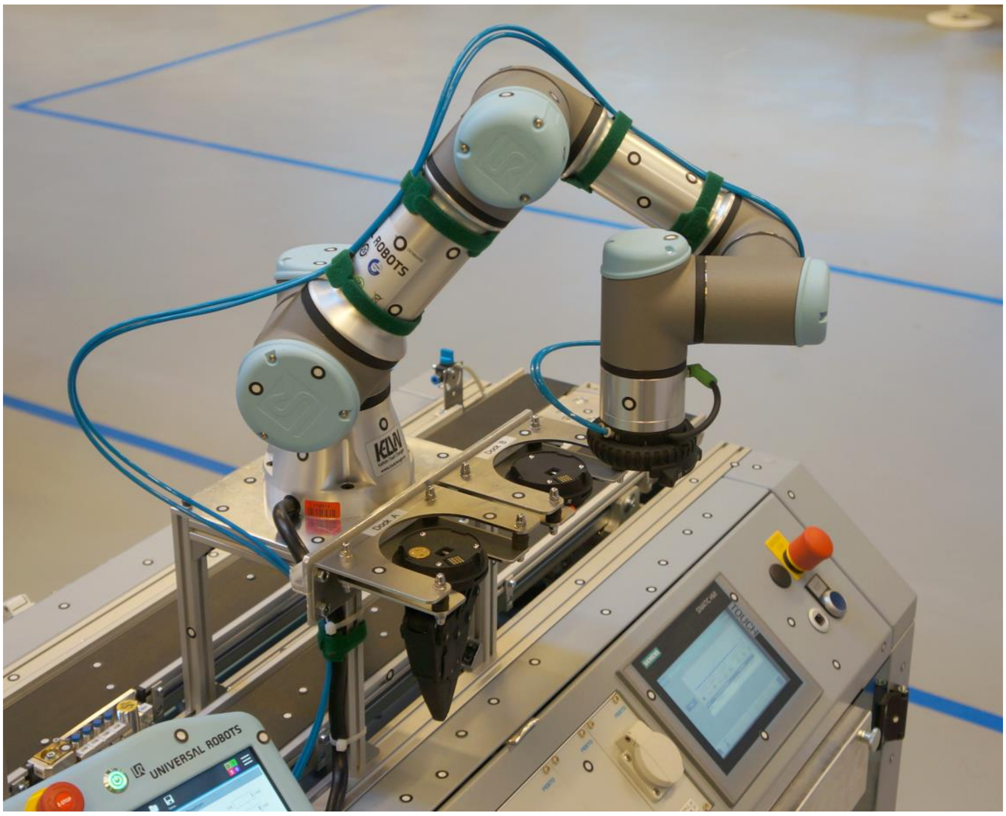
The Kelvin Tool Changer is an automatic end-effector exchange system for small collaborative robots. The tool changer is designed for use in a collaborative environment with close contact between the human operator and the robot.

With the Kelvin Tool Changer, the robot arm can be programed to change automatically from one tool to another.

The tool changer can also be operated manually by the operator.

The tool changer has a very high repeatability but is only suitable for light workload.

The tool changer gives feedback on the status of the coupler and can identify the connected tool by a built-in ID number.



Universal Robot UR3e set up with Kelvin Tool Changer at Smart-LAB at Aalborg University

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2 Scope of Delivery

2.1 What is in the Box

A tool changer system basically consists of a master plate that will be mounted on the robot arm, two tool plates that will be mounted with tools for the robot and two docking stations where the tool plates will be parked. Each of these items is packed in a separate box.

The box with the master plate also contains a USB stick with a program for the UR robot controller, 4 aluminum M6 screws for mounting the master plate, a torque limiting key and a quick mounting instruction.

At the end of the box with the tool plate a label indicates if the tool plate is mounted with electric and pneumatic connectors.

Standard tool plates are equipped with pneumatic connectors.
For tool plates without this connector the position for the pneumatic connection is closed by a plug marked “Pneu”. The tool plate can later be updated with a pneumatic connector (see chapter 5.9).

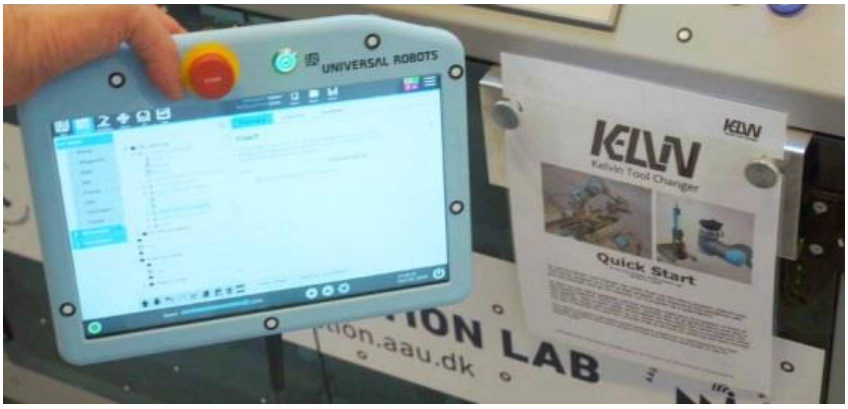
Each tool plate has a built-in tool ID. This indication number can be found as a small number mark inside the opening at the center of the tool plate (see chapter 5.8). The tool ID number is also indicated on the box for each tool plate.

Each docking station is packed in a box with an instruction for mounting and a set of labels. The instruction includes a 1:1 drawing for mounting holes.

The master plate is packed in a box together with a plastic bag containing a torque limiting key, four M6x16 aluminum screws and a small bag with spare parts.

In addition to the individual boxes the delivery includes a printed version of the user manual (this document), a printed quick start document and a packing list. Documents for CE marking are included in the user manual.

The “Quick Start” can be placed on the mount for the UR teach pendant. The “Quick Start” description can also be found at the end of this manual (see chapter 19).



2.2 What is not in the Box

Screws for mounting the tools on the tool plate and screws for mounting the docking stations are not included in the packet.

The Kelvin Tool Changer is designed for the tool flange on Universal Robots (ISO 9409-1-50-4-M6).

4TECH Robotics produces an adapter flange that will fit the tool changer to robots with the smaller ISO 9409-1-31.5-4-M5 flange.
These adapter flanges have a built-in socket similar to the tool socket on UR robots (Lumberg RKMW 8-354).
More information on: www.toolchanger.eu

2.3 Important Safety Notice

Robots are partly completed machinery and thus a risk assessment is required for each installation of the robot.

The Kelvin Tool Changer is CE marked as an independent unit. This makes it very easy to integrate this unit in a robot setup.

2.4 Where to Find more Information

More information on the Kelvin Tool Changer can be found on the website:

http://www.toolchanger.eu

The website includes an online version of the installation manual as well as a user manual, technical drawings, technical specifications and CE documents.

Information can also be found in the Kelvin demonstration program for UR robots. Run program #40: "Program Information" and step through the popups for information.

The serial number for the tool changer may be coded into this popup.

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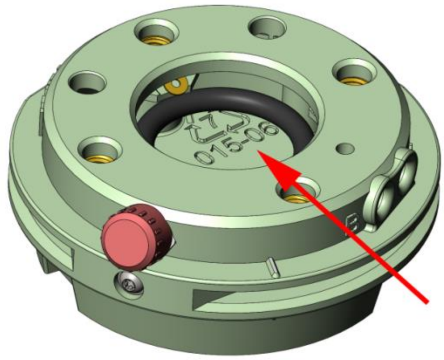
2.5 Machine Plate

The machine plate for the Kelvin Tool Changer is placed on the mounting flange of the master plate.
Only a flap with the CE mark will be visible when the master plate is mounted on the robot arm.

The machine plate is shown here. Serial number and production year are unique for each tool changer.

A copy of the machine plate can be found in the box and in the back of the user manual



Version number for the body of the tool plate can be found inside the tool plate.

Hardware installation manual:

3 Safety

3.1 Introduction

This information on safety must be read and understood by the user of the tool changer before the tool changer is used for the first time. 4TECH Robotics ApS disclaims any and all liability if the tool changer is damaged, changed or modified in any way. 4TECH Robotics ApS cannot be held responsible for any damages caused to the robot, tools or any other equipment due to programing errors or malfunctioning of the tool changer.

3.2 Validity and Responsibility

The complete robot system must be designed and installed in accordance with the safety requirements set forth in the standards and regulations of the country where the robot is installed.
The integrator of the robot is responsible for ensuring that the applicable safety laws and regulations in the country concerned are observed and that any significant hazards in the complete robot application are eliminated.
This includes, but is not limited to:

- Performing a risk assessment for the complete robot system
- Setting up the appropriate safety settings in the software
- Ensuring that the user will not modify any safety measures
- Validating that the total robot system is designed and installed correctly
- Specifying instructions for use

3.3 Limitation of Liability

Any safety information provided in this manual must not be construed as a warranty, by 4TECH Robotics ApS, that the robot will not cause injury or damage, even if the robot complies with all safety instructions.

3.4 General Warnings and Cautions

Make sure the tool changer is properly and securely bolted in place.
Make sure the tools/end effectors are properly and securely bolted to the tool plate.

Make sure the robot arm with the tool changer has ample space to operate freely.

Make sure that safety measures and/or robot safety configuration parameters have been set up to protect programmers, operators and bystanders, as defined in the risk assessment.

Do not wear loose clothing or jewelry when working with the robot. Make sure long hair is tied back when working with the robot.

Never use the tool changer if it is damaged, for example if the release ring is loose or broken.

Do not connect any safety equipment to standard I/O. Use safety-related I/O only.

Make sure to use the correct installation settings (e.g. mass in TCP, TCP offset, safety configuration).

Save and load the installations file along with the program. Be sure to use the installation file that correspond to the program.

Tool/end effectors and obstacles shall not have sharp edges or pinch points.

Make sure to warn people to keep their heads and faces outside the reach of the operating robot or robot about to start operating.

Be aware of robot movement when using the teach pendant.
If determined by the risk assessment, do not enter the safety range of the robot or touch the robot when the system is in operation.

Do not try to disconnect or connect tools manually to the robot arm during operations. Only operate the tool changer manually when the program stops all movements and asks the operator to change the tool. Make sure the tool changer is in the locked position before the program is set to continue operation.

Collisions can release high levels of kinetic energy, which are significantly higher at high speeds and with high payloads.

Combining different machines can increase hazards or create new hazards. Always make an overall risk assessment for the complete installation. Depending on the assessed risk, different levels of functional safety may apply; thus, when different safety and emergency stop performance levels are needed, always choose the highest performance level. Always read and understand the manuals for all equipment used in the installation.

Never modify the tool changer. A modification might create hazards that are unforeseen by the integrator. All authorized reassembling shall be done according to the newest version of all relevant service manuals.

Make sure the users of the robot are informed of the location of the emergency stop button(s) and are instructed to activate the emergency stop in case of emergency or abnormal situations.

When the robot is combined, or working, with machines capable of damaging the robot, it is highly recommended to test all functions and the robot program separately. It is also recommended to test the robot program using temporary waypoints outside the workspace of other machines.

Stay clear of the area around the docking station when the robot arm is about to drop off or pick up a tool. There is a risk of getting pinched between the robot arm and the docking station.
Make sure there is space for movement of robot arm and tools during the tool drop-off and pick-up sequences.

Do not operate the robot if the program does not match the tool mounted on the tool changer.

Do not try to place or remove tools from the docking stations while the robot is operating. Be sure only to place tools in docking stations according to the program that are to be running on the robot.
Make sure the spring-loaded index ball in the tool plate is engaged with the indexing notch in the docking plate. Do not try to let the robot pick up a tool from a docking station if the tool plate is not in correct position in the docking station.

Do not touch the electric contact pins or contact pads inside the tool changer. Do not touch the contact pins or pads with tools or any conducting materials.

Do not open or try to open the master plate. Warranty will be voided and there are no serviceable parts inside. If the back plate is opened on the master plate there is a high risk that parts will fall out or get misplaced inside, causing the tool changer not to function.

3.5 Intended Use

The Kelvin Tool Changer is a device intended to connect end-effectors to a robot arm. The tool changer is a quick connector that allows tools to be connected and disconnected to a robot arm with a simple operation of the locking ring on the master plate. As a part of the physical connection between the master plate and the tool plate both electric and pneumatic connections are established when the tool changer is in the locked position.

When a tool plate is placed in a docking station the robot arm can perform this locking or unlocking procedure by a simple movement of the robot arm.
The arm movements that connect or disconnect the tool can be programed as a sequence to allow the robot to change tools automatically.

Collaborative robots are equipped with special safety-related features, which are purposely designed to enable collaborative operation, the robot system operating without fences and/or together with humans. Any use or application deviating from intended use is deemed to be impermissible misuse. This includes, but is not limited to:

- Use in potentially explosive environments
- Use in medical and life critical applications
- Use before performing a risk assessment
- Use outside of stated specifications
- Operation outside the permissible operating parameters

3.6 Risk Assessment

The integrator must do a risk assessment. The robot itself is partly completed machinery, as the safety of the robot installation depends on how the robot is integrated (e.g. tool/end effector, obstacles and other machines).
It is recommended to apply ISO 12100 and ISO 10218-2 to conduct the risk assessment. Additionally, the integrator can choose to use the Technical Specification ISO/TS 15066 and the ISO/TR 20218-1 as additional guidance.

Safety-related features designed for collaborative robot applications must be set up in the safety configuration settings and addressed in the risk assessment:

- Force and power limiting: Used to reduce clamping forces and pressures exerted by the robot in the direction of movement in case of collisions between the robot and the operator. Also used to reduce the risk of pinching between the docking station and the tool plate during drop-off or pick-up operation.
- Momentum limiting: Reduces high impact forces in case of collisions between robot and operator.
- Position limiting of joint, elbow and tools: Reduces risks associated with certain body parts like head and neck.
- Tool orientation limiting: To reduce risks associated with certain areas and features of the tool and workpiece.
- Speed limitation: Particularly used to ensure a low speed of the robot arm.

The risk assessment must address contacts that are intentional or due to misuse:
• Severity of individual potential collisions
• Likeliness of occurrence of individual potential collisions
• Possibility to avoid individual potential collisions

Potential significant hazards listed below as hazards that must be considered by the integrator. Other significant hazards can be present in a specific robot installation.

1. Penetration of skin by sharp edges and sharp points on tool/end effector or tool/end effector connector.
2. Penetration of skin by sharp edges and sharp points on obstacles near the robot track.
3. Bruising due to contact with the robot.
4. Sprain or bone fracture due to strokes between a heavy payload and a hard surface.
5. Consequences due to loose bolts that hold the robot arm or tool/end effector.
6. Items falling out of tool/end effector, e.g. due to a poor grip or power interruption.

3.7 Pre-use Assessment

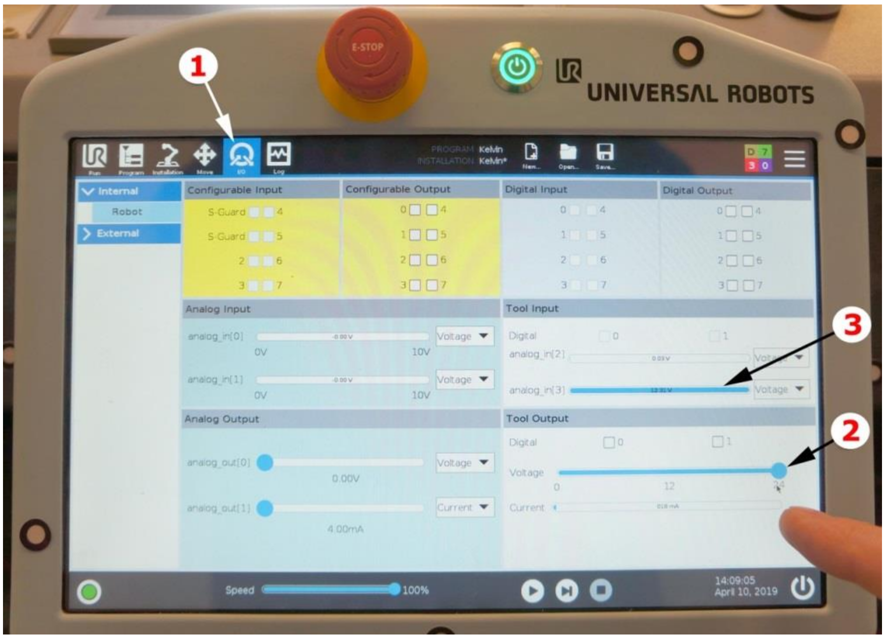
The following tests must be conducted before using the tool changer for the first time or after any modifications are made.

Verify that signal and power cable is appropriately and correctly connected from the master plate to the tool connector on the robot arm.

On the teach pendant choose "I/0" to see in- and output on the robot controller. In "Tool Output" set the tool voltage to 24V. In "Tool Input" the "analog_in[3]" will show the voltage response from the tool changer

When the locking ring on the master plate is turned into the fully open position the voltage on "analog_in[3]" will be 0.
When you turn the locking ring into the locked position (no tool plate mounted) the "analog_in[3]" will show 2.1 V.

Manually mount a tool plate and turn the locking ring to the fully locked position. When the lock ring reaches the fully locked position the voltage reading for "analog_in[3]" will reflect the ID in the tool plate.



On this image the "analog_in[3]" is 12.31 V. This voltage level indicates the ID-8 in the tool plate. See voltage levels for other tool IDs in chapter 6.6.

3.8 Emergency Stop

Activate the emergency stop push-button to immediately stop all robot motion.

In the event of an emergency stop the tool changer will not release the tool plate.

During an emergency stop the tool plate can be disconnected manually from the master plate by turning the locking ring to the open position. This will also disconnect the power supply to the tool.
See chapter 5.6 for more information on manual operation.

If the tool plate is released during operation the program can be set to stop the robot. Manual operation of the tool changer shall only be allowed when the robot arm is not moving.

The emergency stop shall not be used to prevent the robot from starting or moving. Stop the program, turn off the power and disconnect the power connection to the robot controller to make sure the robot will not move or start operating.

The emergency stop must not be activated just for demonstration.

The emergency stop function shall be tested at least once a year. This test must be done as a part of the maintenance program. See chapter 12.4.

3.9 Program Stop

To prevent the robot from getting into potentially dangerous situations the Kelvin demonstration program has some built-in stopping functions. These stop functions are a part of the program for the robot, not a part of the safety system for the robot. This stop function in the program can and shall not replace the safety system for the robot.

One program stop is based on a “thread” in the program. This thread (Thread_1) is a small program that will run in the background and at short intervals will check if the tool is locked to the tool changer.
If the tool changer is not in the locked position the main program for the robot will stop and show a popup error message.
This popup announces “Hook is not in locked position” and is labeled with “Thread_1”.

To allow tools to be replaced by the tool changer a variable (ToolFree) can be set to “1” to block the program stop. Right before a tool drop-off the program sets “ToolFree=1” and right after the next tool pick-up the program again sets “ToolFree=0”.

If an eager operator tries to manually release a tool during operation this program stop will stop the program and prevent a dangerous situation.

This program stop based on releasing the tool can be disabled in the program by suppressing Thread_1.

All standard movements in the Kelvin demonstration program are based on waypoints. All these waypoints are specific for each robot installation and have to be set up before it is safe to let the robot perform these movements.
To prevent the robot from running programs containing waypoints that have not been set up all move commands are set up with a popup that blocks the function. When the user or integrator has set up a waypoint for a movement the blocking stop-popup for this movement can be suppressed.

If a programmer calls a function or subprogram that is not ready to run, he will get a stop-popup that blocks the program.

Each stop-popup is labeled with a unique number to make it easier to find the right stop-popup in the code.

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4 Transport/Handling

4.1 Handling the Tool Changer

When the master plate is not mounted on a robot arm it is recommended to connect it to a tool plate and turn the locking ring into the locked position. This will protect the electric and pneumatic connections inside the tool changer.

Place a tool plate in the master plate and hold the two parts together by pressing the two flange plates. Turn the locking ring into the locked position.

4.2 Protecting Electric Connections

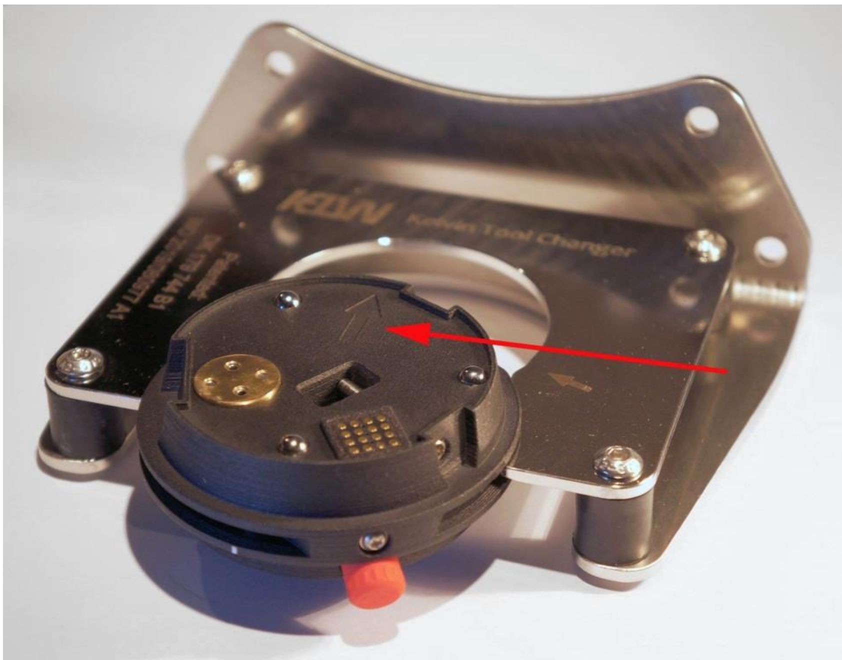
Avoid touching the electric connection inside the tool changer. The grease from fingers may later cause dust to build up on the gold-plated connection pins and pads.

To protect the tool socket, it is recommended to mount the small protection cap on the socket. See also chapter 6.5.

4.3 Tool Plate Parked in Docking Station

A free tool plate may be placed in a docking station during handling or transportation.
Insert the tool plate in the dock plate and turn it into the locked position. This will keep the tool plate from falling out of the docking station.

The arrow marking inside the tool plate shows the direction for mounting the tool plate into the docking plate.



5 Mechanical Interfaces

5.1 Introduction

The mechanical interface of the tool plate is similar to the interface of the robot arm. Tools that can be mounted on the Universal Robot tool plate can also be mounted on the Kelvin Tool Plate.
When a tool plate is connected to the master plate the tool changer will act simply as an extender between the robot arm and the tool.

The ring around the core of the master plate activates the locking mechanism inside the tool changer. This allows the tool plate to be separated from the master plate. Tool plates with different tools can be connected to the master plate.
When a tool plate is mounted on the master plate internal connection for electric power, signals and pneumatic lines are established automatically.

The robot arm can be programed to slide the tool plate into a docking station and activate the locking ring by rotating the robot arm. By doing so the robot arms can drop off or pick up a tool from the docking station. This allows the robot arm automatically to switch between different tools.

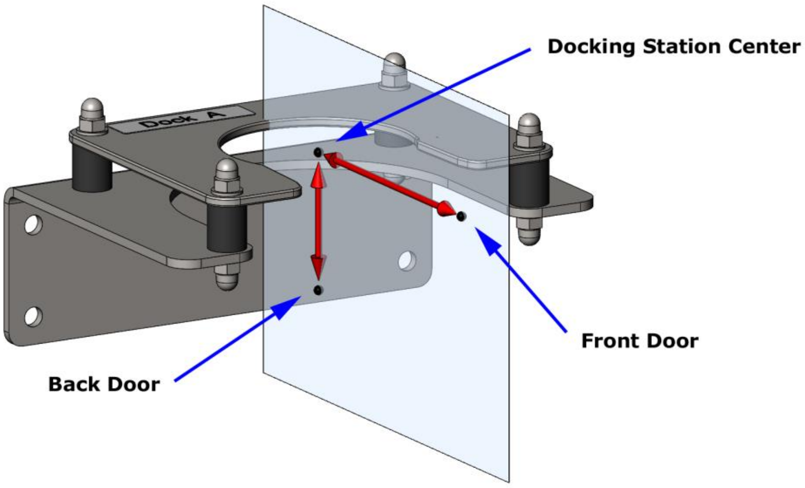
5.2 Workspace of the Tool Changer

The tool changer needs some free space to pick up and drop off tools. There must be enough space in front of the docking station for the robot arm to insert the tool plate into the docking station and there must be space under the docking station for the robot arm to engage and disengage with the tool plate in the docking station.

Tool drop-off and pick-up operations are done by series of movement of the robot arm. All these movements are relative to the center of the docking station. A drop-off operation starts in front of the docking station. This position is called “Front Door”. The pick-up operation will end in the same position.

After the tool is parked in the docking station the robot arm will end in a position beneath the docking station. This position is called “Back Door” and it is also from this position a pick-up operation will start.

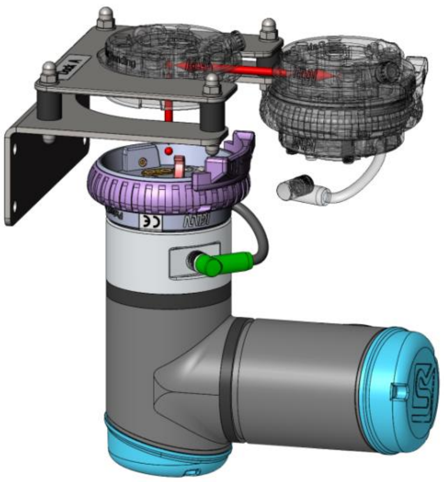
These tree points, docking station center, front door and back door are specific for each docking station.

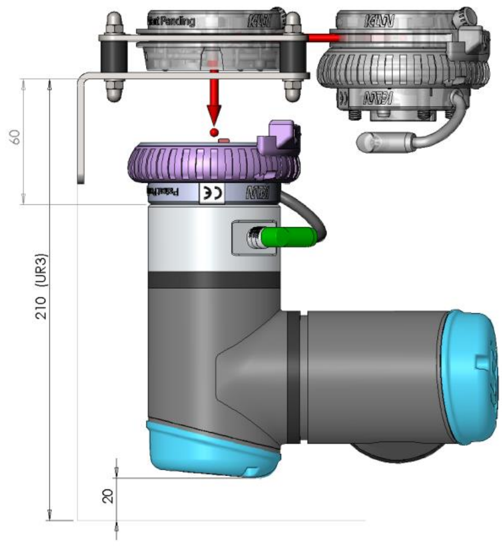


The robot arm with the master plate (no tool mounted) must also be able to move to the back door of one docking station to the back door of another docking station.

The space required under the docking station depends on the size of the robot arm. In general tree dimensions need to be known to find the minimum free space under the docking station. During the tool drop-off the master plate will move 45 mm down to get free of the docking station.

Some minimum of free space under the robot arm will also be needed, typical 20 mm. The size of the robot arm must be added to these to values. For the Universal Robots the free space under a Docking Station must be 210 mm for UR3, 250 mm for UR5 and 300 mm for UR10.





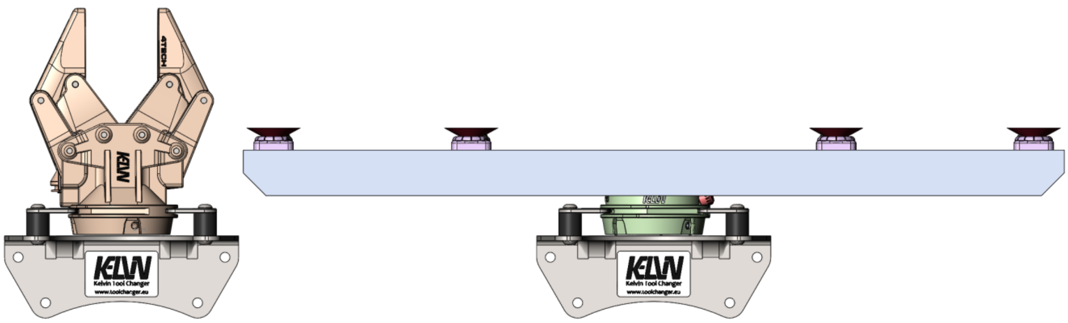
There must be free space for the tool above the docking station. Be aware that the tool will do a rotation movement when it is parked in the docking station. The tool will also be able to move out of its normal position due to the flexing support in the docking station.

It is recommended to park tool plates with the connection facing downwards. This will prevent dust from building up on the electric connection pads. Some tools may be parked otherwise. A gripper with suction cups may be parked with the suction pads downwards to prevent dust from building up on the suction cups.

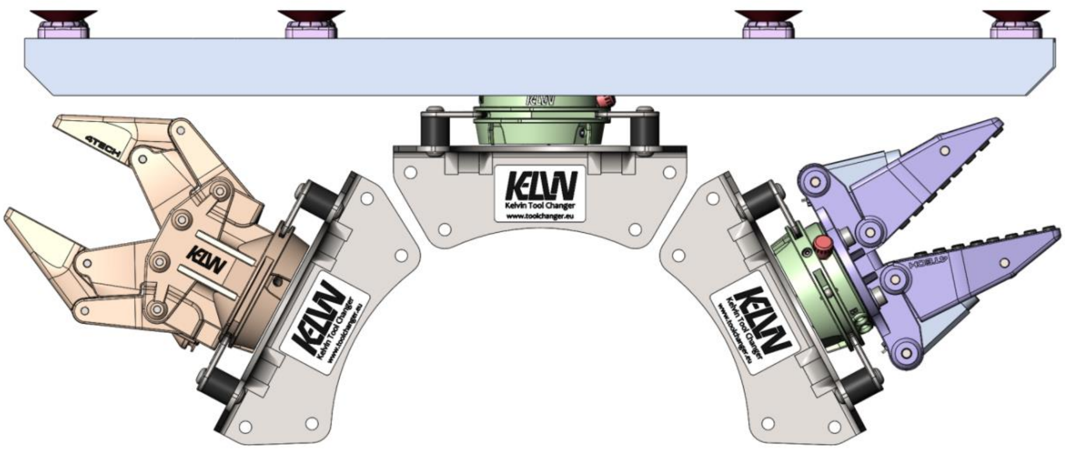
Tools like mechanical grippers may normally be closed when they are parked in the docking station but if tools, for any reason, are parked in an open configuration they will take up more space.
It is recommended to have free space enough for any tool in a docking station to give room for the tool in its most extreme configuration.

Tools that are asymmetrical to the tool plate must be parked vertically (tool up or tool down). An asymmetrical tool parked e.g. horizontally in a docking station may turn the tool plate out of position after it is parked. This can make it difficult or even impossible to pick up the tool again.

If docking stations are placed close together the distance between them must be big enough to prevent two neighboring tools from colliding, even in an extreme situation.



Docking stations can often be placed together in a manner that allows them to share the free space under the docking station.



It is recommended not to place docking stations in a position that force the robot arm to an extreme position. For the Universal Robot see “Workspace of the Robot”.

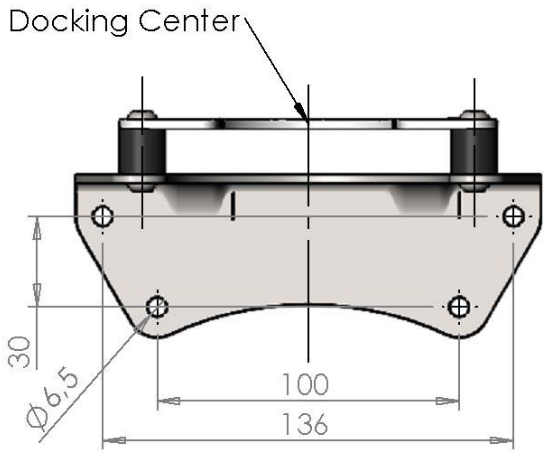
The docking station should also be placed well away from operators. The tool pick-up and drop-off sequence have potential risk of an operator to be pinched between the docking station and the robot arm. By choosing positions for the docking stations that are well away from operators the risk of pinching or hitting the operator can be reduced.

5.3 Mounting the Docking Station

It is recommended to place the docking stations well away from the operator to reduce the risk of an operator being pinched between the robot and the docking station.

The docking station must be mounted on a rigid support that will not flex or rotate when a tool is parked in the docking station. The support should also be strong enough to withstand a mishap where the robot arm collides with the docking station.

The docking station is mounted with 4 screws through the mounting holes. The docking station comes with a 1:1 drawing for easy marking up of the mounting hole for the dock.



See chapter 5.2 for more information on the space between and around docking stations.

Each docking station should be given a unique number. This number can be marked on the docking station by means of the labels delivered with the docking station. In the UR demo program for the automatic tool drop-off or pick-up this name is to be used as a reference for the parking position.

If an operator or service person needs to remove or place a tool in a docking station it is recommended to use the "Tool Service" program to perform this operation. This program picks up or drops off a tool to a docking station and allows the operator to manually change the tool when the robot arm is at a safe position for this operation (Dock M).

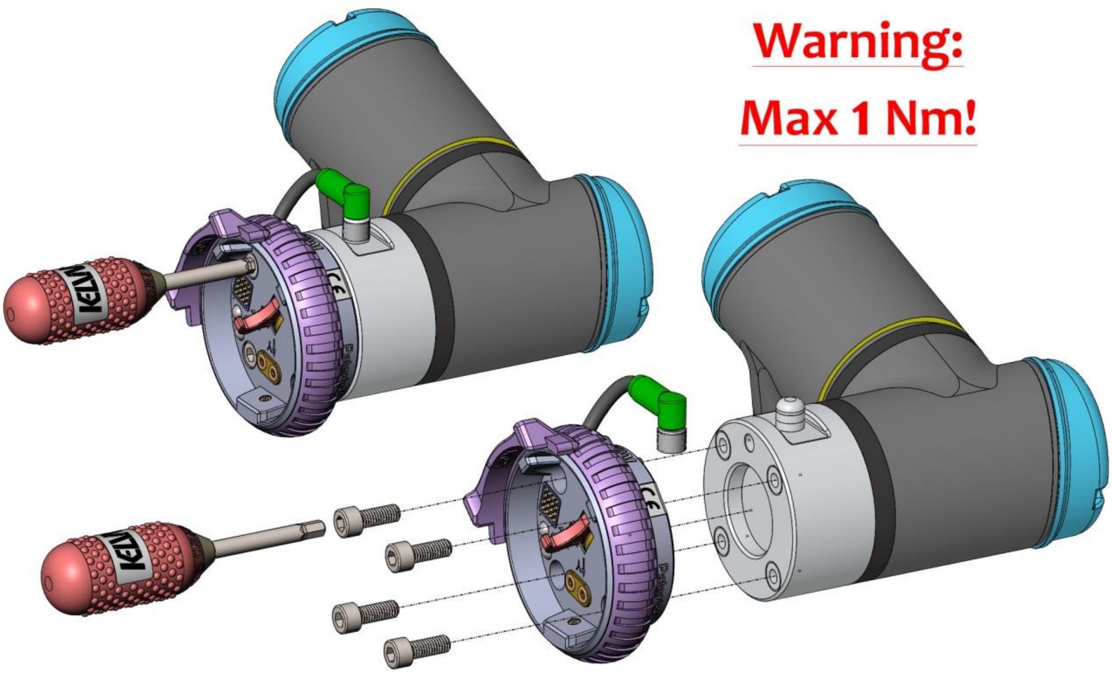
See more information on the manual docking station in chapter 9.9.

5.4 Mounting the Master Plate

The master plate is mounted on the UR robot arm with the four aluminum screws delivered in the box. The master plate has a built-in index pin at the mounting flange. This pin must fit into the index hole in the robot mounting flange.

The housing of the tool changer is made from plastic and can easily be deformed or damaged if the mounting screws are tightened too hard. It is strongly recommended only to use the aluminum screws delivered with the Kelvin Tool Changer and to tighten these screws only with the small red torque limiting screwdriver.

The mounting screws must never be tightened to more than 1 Nm.



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The torque limiting screwdriver is not able to exceed this maximum mounting torque.

After the master plate is mounted the plug for the electric connection can be connected to the tool socket on the robot arm. Make sure the plug is fully inserted to the socket and that the union nut is tightened.

If the tool changer is to be used with pneumatics the two ø4 mm hoses must be connected to the master plate. The two pneumatic couplers are marked with "A" and "B". The corresponding ports on the tool plate are also marked this way.

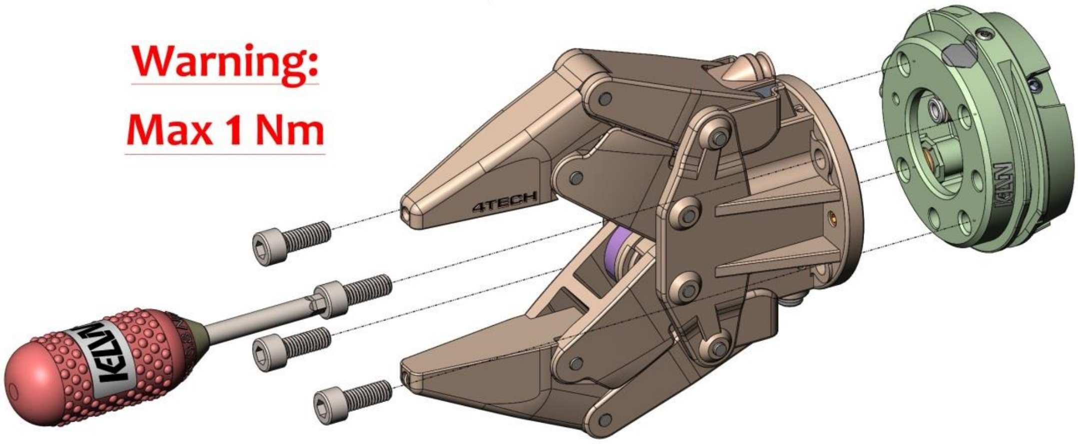
The tool changer does not shut off the pneumatic connections when the tool plate is separated from the master plate. The two pneumatic lines must be shut off by a control valve before the tool plate is parked in the docking station. More info on pneumatic valves in chapter 5.9.

5.5 Mounting the Tool Plate

Mounting the end-effector on tool plate:

The tool plate has three holes for ø6 dowel pins to index the tool. The index hole at the Kelvin logo corresponds to the index hole in the mounting flange on the UR robot arm.

An end-effector is mounted on the tool plate with 4 M6 screws. The max depth of the holes in the tool plate is 12 mm and the screws must be inserted at least 7 mm into the hole. Max torque: 1 Nm. If possible, use the plastic screwdriver with torque restriction from the box.



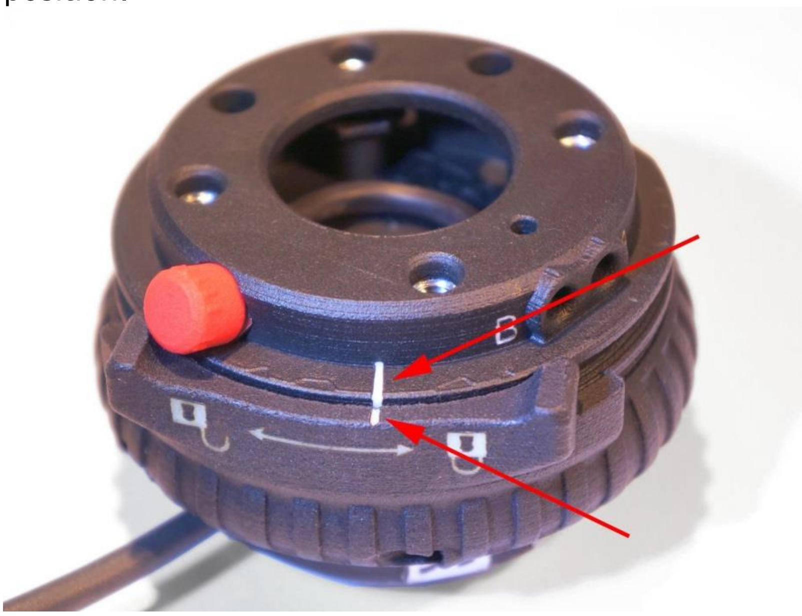
Unscrew the small protecting cap from the tool connector socket and mount the plug for the electric connection to the tool.

It is important that the tool is mounted in such a way that the tool will not become loose or fall off, even if the robot arm makes a hard collision with an obstacle.

5.6 Manual Mounting of a Tool Plate on the Master Plate

This procedure describes how to manually mount a tool fitted with a tool plate on a robot arm fitted with the master plate.

First make sure that the locking ring is turned into the fully open position. Place the tool plate inside the master plate. The coded tongue and grooves ensure that the tool plate can only be inserted in the right way. Turn the locking ring to the locked position. It is important that the locking ring is turned all the way into the locked position. It is easy to feel how the locking mechanism turns over into the self-locking position.



Two markings on the tool plate and the master plate will align when the lock is in the locked position.

The tool plate can be released again by turning the locking ring back to the free position. The pictogram on the ring shows which way to lock or open the tool changer.

Note that the tool plate and tool may drop off from the master plate when the locking ring is turned to the free position. It is recommended to turn the robot arm to a position with the tool in an upright position before the tool is released.

5.7 Tool ID

The Kelvin Tool Changer is able to identify the tool plates when they are connected to the master plate. The tool plates are set up with 10 different ID numbers. The UR e-series robots can detect all these 10 IDs.

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If the voltage for the tool power is set to 24V the UR CS series will only be able to detect up to ID 5. AI_3 is limited to max 10V.

Each tool plate has a built-in ID tag. This ID number can be detected by the robot program and is used to make sure that the robot picks up the right tool.

Tool ID 0 is a little special. It is used for tool plates that do not have an ID tag. It will still be possible to use a tool without an ID tag but the identity of this tool must be considered unsafe and this must be taken into consideration during the programing of the robot.

If the robot does not get a good reading of a tool ID the program will not use this tool. A faulty identification of a tool ID will not be treated as a tool with ID 0. It will be seen as a malfunction and the program will not allow the robot to use this tool.

A tool may also have a non-valid Tool ID. That is if the tool changer is able to detect an ID but the value of this ID is outside the specifications. ID voltage values can be found in chapter 6.6.

It is not recommended to use tools without IDs (ID-0) or with invalid IDs.

If a tool ID does not match the programed value the program will stop and warn the operator. Depending on the safety strategy for the program the operator may be able to overrule this warning and thus still use the tool.

The tool ID is built into the electric connector in the tool plate and a small number tag in the opening for the hook also indicates the ID number for the tool. This number tag can be seen even with a tool mounted on the tool plate.
The number tag has a printed digit but is also color-coded, using the same standard color code as electronic resistors.

Color	Value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

If an even higher security level for the validations of tools is necessary the tools can be marked with a bar code, RFI-tag or a similar system. This kind of tool tracking is not directly supported by the Kelvin program but can be integrated with the robot control system.

5.8 Pneumatic Connections

If the tool plate is equipped with a pneumatic connector two pneumatic hoses, ø4 mm, can be connected to the pneumatic connectors inside the tool plate. The pneumatic ports are marked with "A" and "B" referring to the similar markings on the pneumatic connectors in the master plate.

The internal opening in the master pneumatic connector is ø1.5 mm and the internal opening in the tool pneumatic connector is ø1.3 mm

If a tool plate is not mounted with a pneumatic coupler the position for the pneumatic connector is fitted with a blind marked "Pneu".
This blind can be removed and replaced by a pneumatic connector.
More info in chapter 5.10.

If there is air under pressure in the tool or the hoses connected to the Master Plate when the tool plate is disconnected from the master plate, this air will be released inside the tool changer.

This problem can and should be prevented by releasing the pressure from the tool and hoses before the tool drop-off operation.

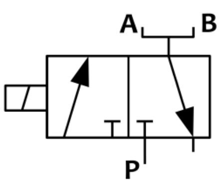
Opening the tool changer with pressure on the pneumatic connector may also misplace or blow off the O-rings in the pneumatic connector.

5.9 Pneumatic Valves

The Kelvin Tool Changer does not have a built-in valve system for controlling the pneumatics. Valves for the pneumatic lines must be mounted separately and connected to the robot controller.
The Kelvin Tool Changer only connects the pneumatic lines between the master plate and the tool plate.

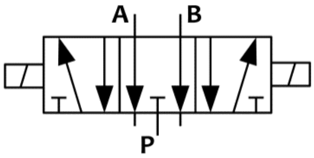
The valve system must be able to block both air hoses when no tools are connected to the tool changer.

If the pneumatics is only used for simple operations such as feeding a vacuum injector or a simple spring return actuator, the two lines can be operated in parallel. This can be done with a simple 3-2 valve.

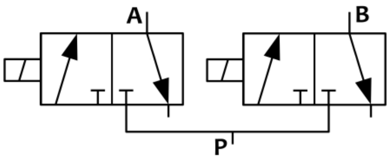


If the pneumatics is used to run a double acting cylinder, it should be possible to apply air supply to each of the two lines. This is typically done by a 5-2 valve.

With a tool changer it is also necessary to block the air supply to both lines when the tool is not connected to the tool changer.
This can be done by a 5-3 valve with a closed center position or by letting a valve cut off the air supply to the 5-2 valve.



An even smarter way to manage the two pneumatic lines is to use two 3-2 valves. The two 3-2 valves can be operated similarly to a 5-3 valve to control a double acting cylinder. By closing both valves, the air supply can be shut off when no tool is connected. This is similar to the closed center position for the 5-3 valve. The real advantage of a setup with two 3-2 valves is that the two lines can also be opened in parallel and give a high flow to a tool with e.g. a vacuum injector.



Like a 5-3 valve the double 3-2 valve setup only takes two signals outputs from the controller, but the opportunity of opening both valves at the same time makes it possible to give high flow to the tool.

5.10 Retrofit Pneumatic Connector on Tool Plate

A tool plate can be updated with a pneumatic connector.
From behind, first push out the blind to make space for the connector.
Put the two M2.5 screws into the holes and mount the pneumatic connector from the front. The connector is symmetrical. Tighten the two screws to 0.2 Nm.

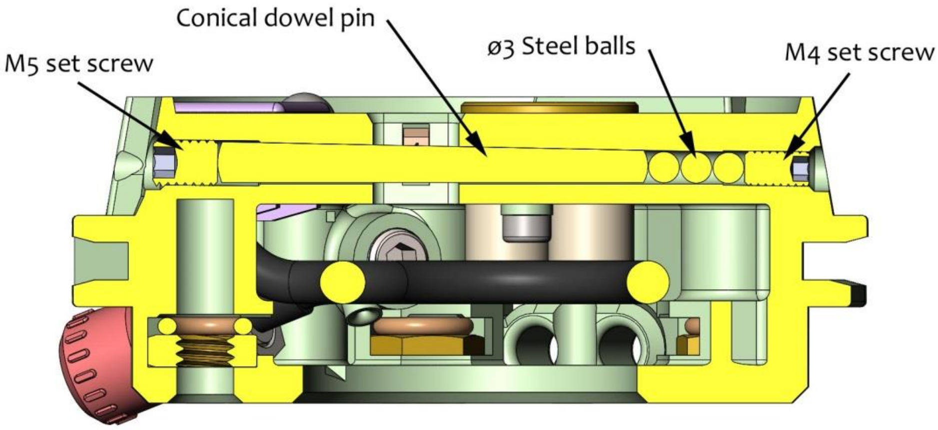
Hoses might be mounted in the fittings before the connector is inserted and the screws tightened.

5.11 Adjusting the Master Plate – Tool Plate Connection

The connection between the master plate and the tool plate can be adjusted on the tool plate. The small steel dowel pin that the hook grabs on to is conical and will act as a verge if it is moved sidewards. This conical dowel pin is held in position by a set screw from each side. Some small steel balls are used to give the conical dowel pin the right position.

The dowel pin is adjusted from the factory to compensate for any tolerances in the parts. It is not recommended but it is still possible to change the connecting force by moving the conical dowel pin to a new position.

The position of the conical dowel pin can be adjusted by moving steel balls from one end of the conical dowel pin to the other. The set screws only stop the steel balls from falling out and only have to be tightened very lightly.



5.12 Tool Center Point, TCP

The robot program requires information on the geometry of the tool fitted on the robot arm. By setting up a center point for a tool the robot program can move the robot arm relative to this point and e.g. follow a path or pick up objects.

For robots with one permanent mounted tool (no tool changer) this "Tool CenterPoint" or TCP is only set up once and then used for all programs with the robot.
With a tool changer the robot program must switch TCP as it shifts between tools. The empty tool changer is also considered as a tool and has its own TCP.

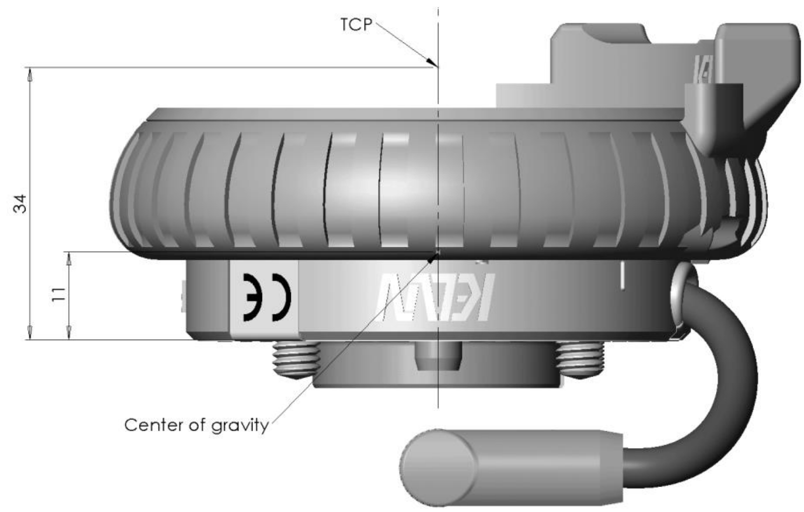
Universal Robots have the center of the tool flange as the default TCP. The center of the tool changer is TCP-1 and is used for operations with the tool changer. More TCPs must be set up for the tools used with the tool changer.

Tool Center Point:

TCP	Tool mounting flange on robot arm (UR default, not used)
TCP_1	Tool changer center. Used for all docking operations
TCP_2	(free)
TCP_3	(free)

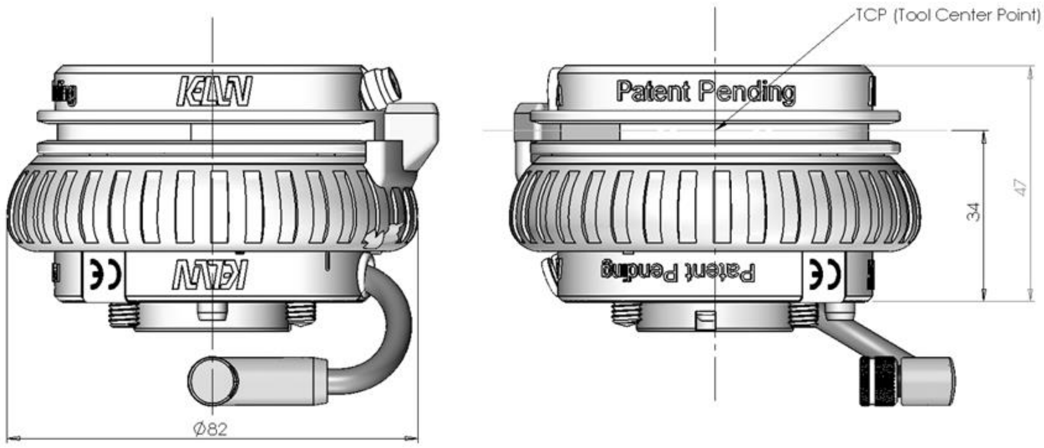
TCP_1: (x,y,z): (0,0,34) mm

Weight, only master plate: 155 g
Center of gravity: (CGx, CGy, CGz): (0,0,11) mm



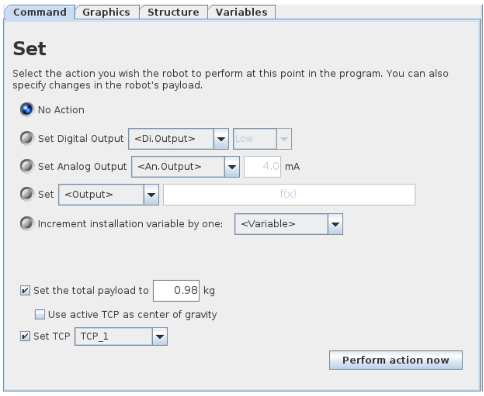
TCP for New Tools:

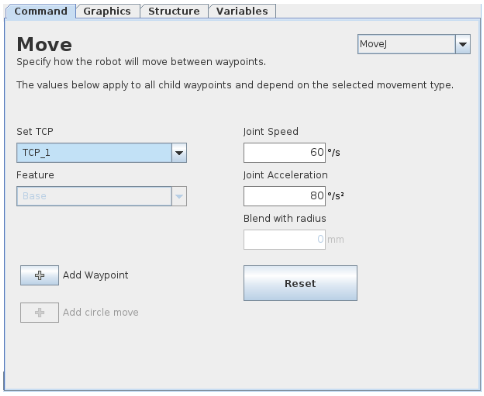
When a new tool is to be used with the tool changer the TCP can be found by adding 47 mm to the z-value.



Using TCP in Programing:

In the UR program the TCP can be specified with the “Set” command and in the “Move” command.



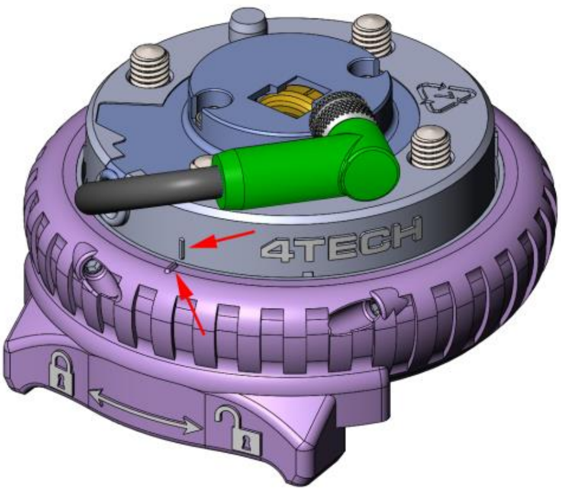


See chapter 9.5 on how to set up TCP in the Kelvin demonstration program.

5.13 Hook Position

The two parts of the tool changer are held together by a hook. During the tool pick-up process the position of the hook is checked by the program. Before the tool changer will try to connect to a tool in a docking station the hook must be in the fully open position and when a tool has been picked up by the tool changer the hook must be in the locked position. If the hook is not in the fully open or locked position the program will stop and ask the operator to solve the problem.

The hook is manually operated by turning the locking ring. Pictograms on the locking ring indicate which direction to turn the locking ring to lock or unlock the tool changer.

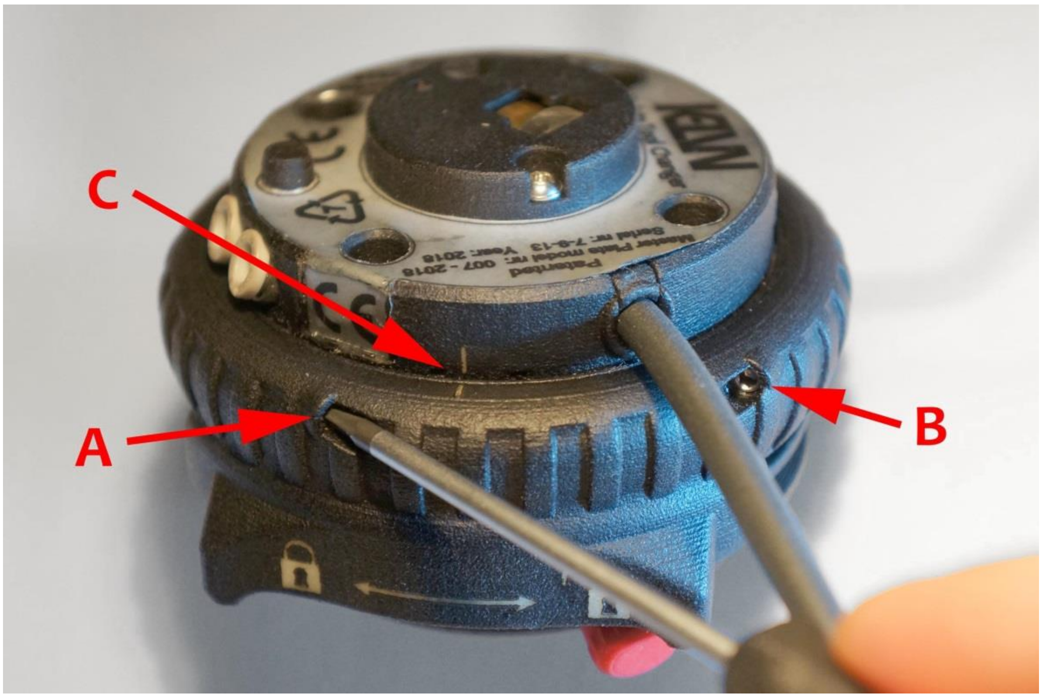


When locking the connection, it is important to turn the locking ring into the fully locked position. Two markings on the tool changer will also indicate the locked position. If the hook is not in the locked position the program will not accept to use the tool. This is for your safety.

5.14 Adjusting Locking Ring Clearance

The locking ring and locking mechanism need a small clearance or slack to function well. This clearance is set by the manufacturer but can later be adjusted on the master plate. The clearance is controlled by two sets of screws in the locking ring but the combination of these two screws also adjusts the position of the locking ring when the tool changer is in the locked position.

To adjust the clearance and the position of the locking ring mount a tool plate on the master plate and turn the locking ring into the locked position. With a 2 mm hex key the two sets of screws (A and B) can be moved in and out.



Moving the two screws out will give more clearance and moving both in will give less clearance. The clearance should be as small as possible but there must be a clearance. The right clearance will allow the locking ring to move 1 mm at the line-up marking (C).

The position of the locking ring can be adjusted by moving one screw in and the other out. The two markings (C) shall line up when the locking ring is in the locked position.

6 Electrical Interfaces

6.1 Introduction

For the Universal Robot the master plate is connected to the tool socket on the robot arm. The tool plate has a tool socket similar to the tool socket on the UR robot arm. Most of the connections in the tool socket on the robot arm will be connected directly to the tool socket on the tool plate.

If the Kelvin Tool Changer is used with other robot arms the master plate must also be connected to the robot controller. In this case it is strongly recommended to connect the wires the same way as on the UR robots. Tools mounted on the tool plate and connected to the socket on the tool plate are likely to be tools designed for the UR robot.

The Kelvin Tool Changer may also be mounted on robots by the adapter plate from 4TECH Robotics. See chapter 2.2.

6.2 Power Supply

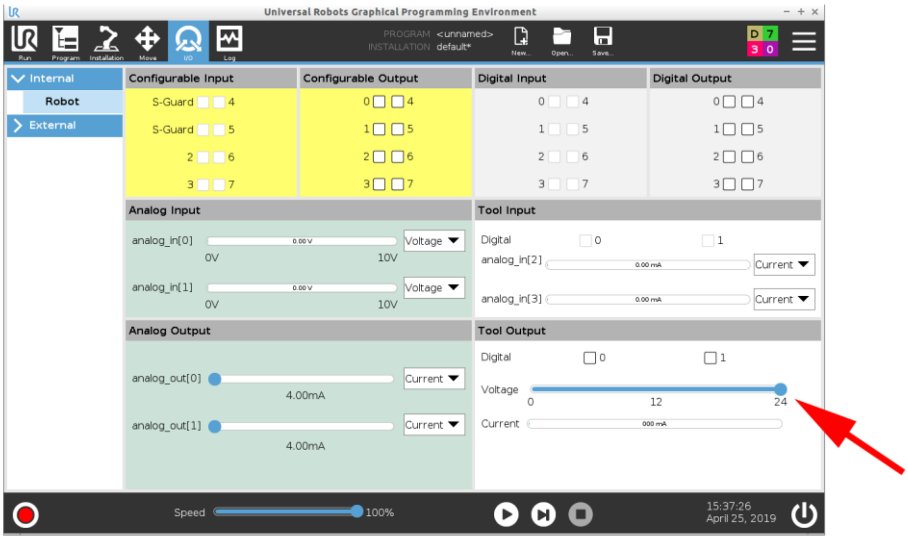
The Kelvin Tool Changer needs power supply to detect the position of the locking mechanism and to detect tool IDs.
Mechanically the tool changer will function without power supply but not all safety functions checking the tool changer status and tool ID will be possible.

When the master plate is open and not connected to a tool plate the electric connector inside the tool changer is visible but the power (e.g. +12 or +24V) is not connected to these gold-plated connector pins. The ground connector, digital in- and outputs and the analog in- and output are always connected to the robot arm.

The Kelvin Tool Changer will operate on both 12- and 24-volt power supply from the tool connector socket on the robot arm. The Kelvin program must be set up for the actual voltage. As default the demo program is set up for 24V.

If you need to change the power supply to 12V or another voltage the Kelvin program must be adjusted to reflect this voltage level. In the UR program this can be done in the "BackUp" program (Kelvin program #45, see chapter 9.11).

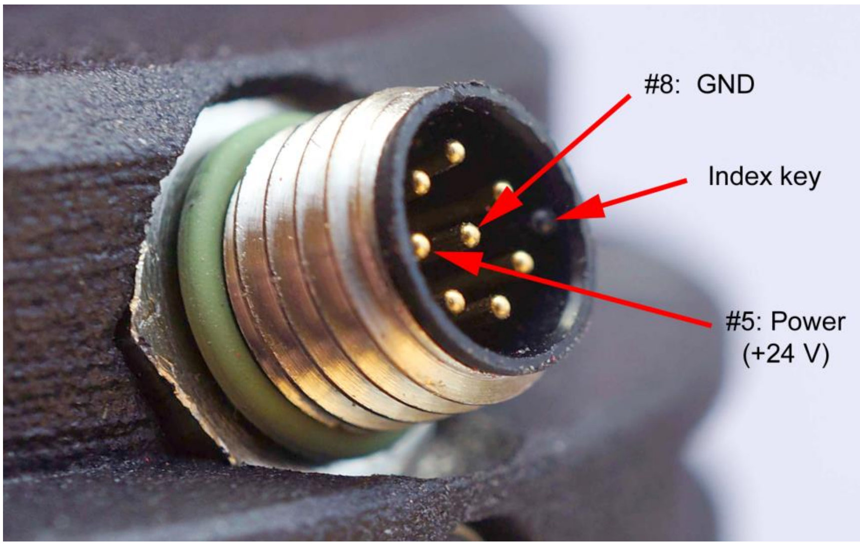
It is possible to program the Universal Robot to change between 12V and 24V if different tools need different power supplies. It is also possible to program the tool changer to follow this change in the voltage setting.



The power supply (+24 or +12V) from the tool socket on the robot arm is transferred to the power socket on the tool changer tool plate.

When the tool changer picks up a tool the power supply is not connected before the tool changer is fully connected and the locking mechanism is in the locked position.
In the same way when the tool changer drops off a tool the power connection is disconnected before the tool is mechanically disconnected. This prevents sparks from eroding the contact pins and pads. It also protects the tool from power-up and power-down during tool changer operations.

It is only the power supply (pin 5) that connects or disconnect when the hook leaves the locked position in the tool changer. Ground (pin 8) and signal connections are not disconnected before the actual tool drop-off.



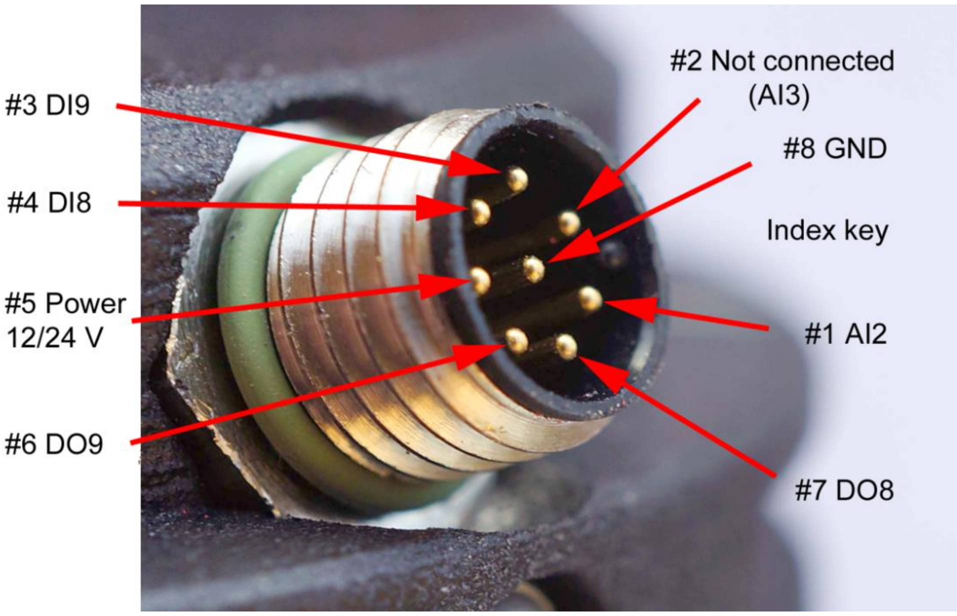
6.3 Tool Changer Status

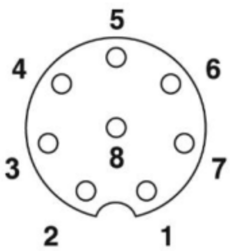
The Kelvin Tool Changer does not use electric power for the locking operation but a mesh of resistors and micro switches form a voltage divider that is used to monitor the status of the tool changer during the tool pick-up and drop-off operations. The voltage output from the mesh is measured by the robot controller via one of the analog inputs in the tool connector. This input (AI3) is not connected to the socket on the tool changer tool plate.

The power supply for the tool connector on the robot arm must be set to 12 or 24V for the tool changer to operate correctly with the UR demo program. 24V setting are recommended. The tool changer will be able to pick up or drop off tools without power supply but the robot controller program will not be able to monitor the process.

6.4 Tool Connections

The pins in the socket on the tool plate are similar to the pins in the socket on the UR robot arm. The only difference is that Pin 2 is not connected (tool analog input 3 – UR: AI3)





Pin	Color	Primary function	Alternate function	Manual function	UR I/O
5	Grey	+24V <600mA	+24V <1500mA		Power
8	Red	GND / 0V / Shield			0V/GND
7	Blue	Data input (npn)	Data input (pnp)	CHA On/Off	DO8/TO0
6	Pink	Data input (npn)	Data input (pnp)	CHB On/Off	DO9/TO1
4	Yellow	Data output (pnp)		CHA vacuum OK	DI8/TI0
3	Green	Data output (pnp)		CHB vacuum OK	DI9/TI1
1	White	Analog output	MODBUS RS485 (-)	CHA vacuum %	AI2
2	Brown	Analog output	MODBUS RS485 (+)	CHB vacuum %	AI3

6.5 Electrical Warnings and Cautions

Do not touch the connectors inside the master plate.
Some of the gold-plated connectors are directly connected to the robot controller. Touching these connectors may send a static electric chock into the controller.

Touching the connectors may also leave grease or moisture from your fingers on the contact surfaces. Over time this may cause dust and dirt to build up on the contacts and could lead to problems with electric contact in the future.

If the pins or pads start to look dirty or if you experience problems with electric connections the pins and contact pads can be cleaned with soft paper tissue wet in isopropyl alcohol.

If you use a tool plate equipped with a tool socket but do not have a tool attached the connection pins inside this socket will also give direct contact to the controller. It is recommended always to cover unused tool sockets with a protective cap.

An end-effector electric cable plug can be connected to the socket in the tool plate. Make sure that the cable is secured from catching any obstacles during operations.

Do not operate in a wet environment. Humidity must be below dew point. See technical specifications (chapter 7.4) for more information.

6.6 Tool Changer Feedback

The UR demo program for the tool changer will detect tree different stages of the tool changer:

- The master plate is free and with the hook in the open position. The master plate is ready to engage a tool plate in a docking station
- The master plate is at an intermediate stage. The hook is not in the fully open position but also not in the locked position

- The master plate is connected to a tool plate. The hook is in the locked position and a tool plate is connected to the master plate

The electric feedback in the tool changer is designed as a passive circuit that divides the supply voltage. Each stage in the tool changer will give a unique split of the supply voltage. With a given supply voltage it will be possible to calculate the feedback voltage for each stage and tool ID.

For UR robots the tool changer will give feedback on both 12V and 24V. It is possible to see the voltage level of the tool changer feedback on the "I/O" tab during a manual operation of the locking ring on the master plate. See chapter 3.7.

The sample program for the Kelvin Tool Changer is set up to work with fixed values for the feedback signal.

By changing the value of a single variable in the program the feedback signal can be adapted to the actual voltage of the power supply.

This value can be found in the "BeforeStart" section in the program. See chapter 10.2 for more information.

	Hook full open		Hook in locked position										
Power supply	Ready to connect	Intermediate	No Tool ID (ID-0)	Tool ID-1	Tool ID-2	Tool ID-3	Tool ID-4	Tool ID-5	Tool ID-6	Tool ID-7	Tool ID-8	Tool ID-9	Tool ID-10
24V	**0**	**2,1**	**4,9**	**5,7**	**6,7**	**7,4**	**8,4**	**9,5**	**10,8**	**11,7**	**12,4**	**13,2**	**14,1**
12V	**0**	**1,0**	**2,4**	**2,9**	**3,4**	**3,7**	**4,2**	**4,7**	**5,4**	**5,8**	**6,2**	**6,6**	**7,0**

e-Series will detect all Tool-IDs but CB-series will only detect up to ID-5 at 24V

Tolerances for recognizing Tool-ID @ 24V power supply

Max	**0,5**		**5,1**	**5,9**	**6,9**	**7,6**	**8,6**	**9,7**	**11,1**	**12**	**12,8**	**13,6**	**14,5**
Min			**4,6**	**5,5**	**6,5**	**7,2**	**8,2**	**9,2**	**10,5**	**11,4**	**12,1**	**12,9**	**13,7**

If the tool changer is supplied with a different voltage the corresponding voltages for the different states and tool IDs can be calculated. In the program a general correction coefficient can adjust all values to the actual power supply voltage.

More basic information on tool ID in chapter 5.7.

7 Setting up Docking Stations

7.1 Dock Center Point

The docking function in the Kelvin program uses the center position for the docking station as a reference for all the movements it makes to pick up or drop off a tool.

To install a new docking station, it is necessary to find the center position for this new docking station and code it into the Kelvin program.

Once a docking station is set up and the robot is able to dock to this station the Kelvin program has a function for optimizing the position to get a smooth docking. This is Kelvin program number 42.

7.2 Find the Dock Center Point

The position of a new docking station is found by manually moving the robot arm into the docking station. Put the robot arm in "Free Move" and bring the robot arm with the tool plate into the docking station. Try to find the best position where the tool plate is well aligned with the docking plate. If the tool plate is not pushing or twisting the dock plate the robot arm is in the right position.

Open the "Move" menu to see the position of the robot arm. Make sure the position for the robot arms is set to "Base".
In the "TCP" window the six pose coordinates for the docking center will be shown. Write down or make a photo of these six values. Be aware that some of the data might be negative values.

Open the "Installation" tab and find the "Variables" menu. Here the pose for a list of docking stations will be shown. Highlight the dock that is to be set up and chose "Edit Value". Now the pose for this docking station can be updated with the values found with the robot arm in the docking station.

7.3 Test the Docking Station

Once the pose for the new docking station is saved in the Kelvin program it is time to test the docking station.

Set the program speed to a low value and run a program where a tool is dropped off and picked up from this docking station. Demo programs 16 to 19 are set up just for demonstrating the tool changer operations with a docking station.

When new docking stations can pick up and drop off tools it is recommended to use "Kelvin Program 42" to optimize the pose for this docking station.

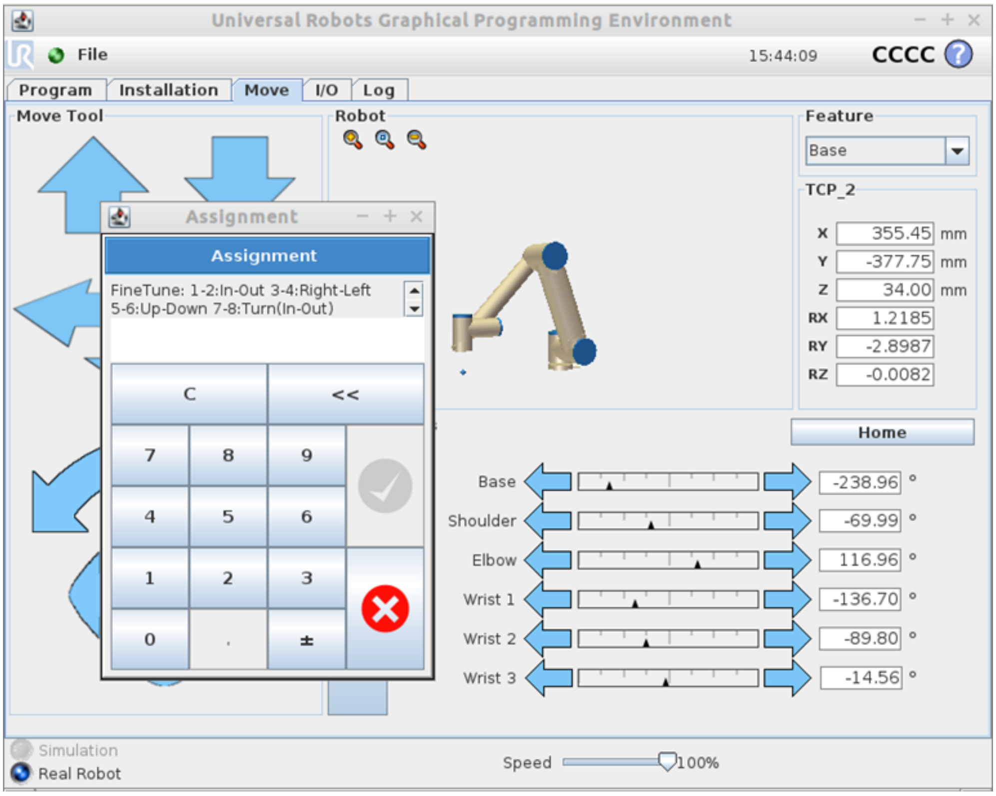
7.4 Adjust a Docking Station Using Program 42

The position for a docking station can be fine-tuned with the Kelvin program: "42: Dock Set-up and adjust".

This program will allow you to make adjustments to the position of a docking station in order to fine-tune the docking operations.

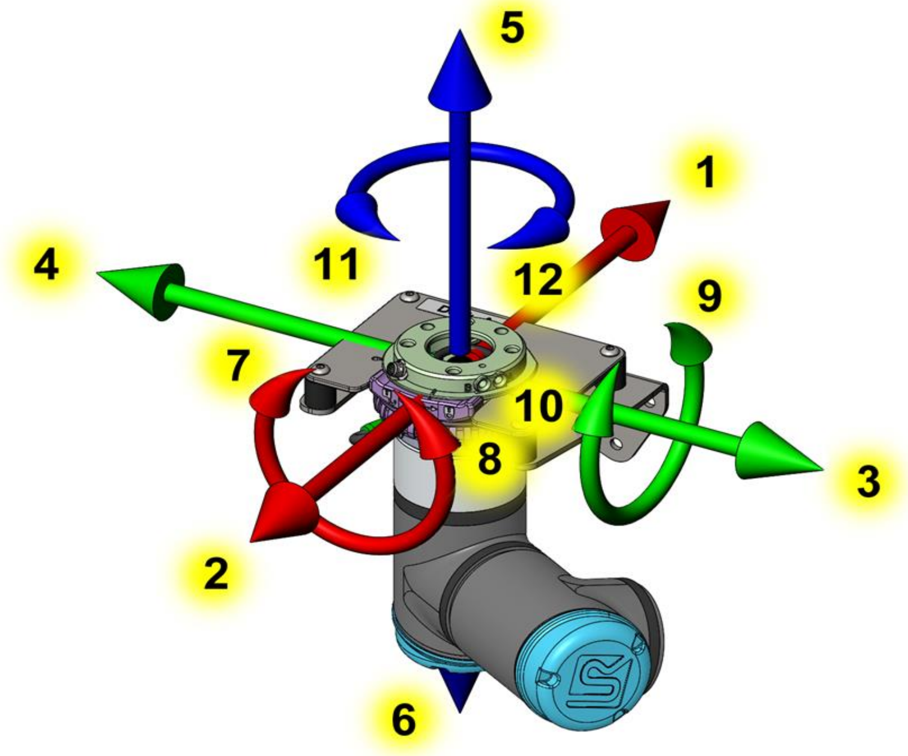
When you run this program, you will first have to choose which docking station to adjust. The robot will move to the docking station and move to the dock center.

In this position you can adjust the position of the robot arm to match the position of the docking station. The program has a function to micro step the robot arm in all directions. The micro steps are very small and it is recommended to overdo adjustments and then step back to the best position.



Small corrections to the position of the robot arm can be done by typing in the number for the directions. Not only can the translation of the positions be adjusted but also the rotation around the 3 axes.

The number for the adjustments can be seen from this sketch:



7.5 Fine-tune the Position

First look for the rubber suspension for the dock plate. If the rubber suspension is deflected in any direction, move the robot arm to release this suspension.

The micro steps for adjusting the robot arm are very small and it can be difficult to see when you are in the right position. A hint is here to overdo the adjustment until you see the robot too far in the opposite direction and then step back to a point between the two extreme positions.

Check for free space between the tool plate and the docking plate. This will give you an indication of any angular misalignment. Using a flashlight to illuminate the background behind the docking plate will make it easier to see spaces between the tool plate and the docking plate.

When you are close to the right position, try to move the docking plate around by hand. If it is easier to move the docking plate in one direction than another this will tell you that the robot needs a small adjustment in this direction.

7.6 Test the New Position

When you have found a good position for the robot it is time to make the first test run with this new position. When the robot is doing the slow drop-off and pick-up you must look for any movements of the tool plate just when it is released and reengaged by the master plate. You must also observe how the tool plate is leaving and entering the docking plate.

The docking plate will flex and compensate for a great deal of misalignment but to get a good lineup for the docking station the tool plate should leave and enter the docking plate as if it does not even touch the plate.

If you find any misalignment you can go back to the fine-tuning program and adjust the position of the robot arm.

After the first slow test run you can run the docking operation at normal speed just to check that the operation is performing as expected.

7.7 Save the New Position

Now the program will save the setup information to this docking station but you will have to restart the Kelvin program before being able to use this setup for the docking station.

If you want to install docking position from a previous setting, choose the back-up routine and choose which docking station you want to be rolled back to a previous position. This is the same backup program as Kelvin Action 43.

Once you have a well-functioning setup for a docking station it is recommended to make a backup of this position. The program will allow you to save the dock position to a backup.

It is recommended that you also save these data by typing the pose for the dock into the program code. Hint: a quick and easy way to make a backup of the dock information is to click on the “Variables” tab and take a photo of the screen when it shows data for the dock.

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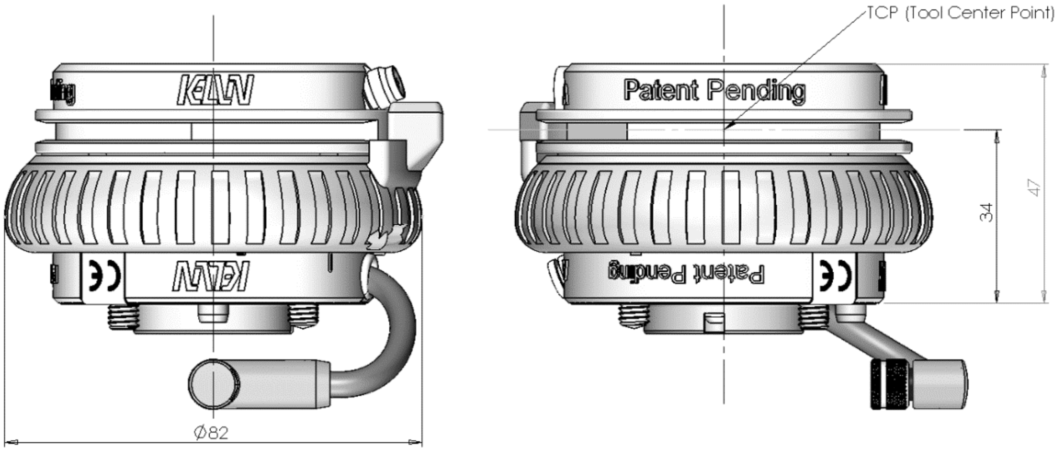
8 Technical Specifications

8.1 Mechanical Dimensions



Weight of a complete tool changer: 240 g

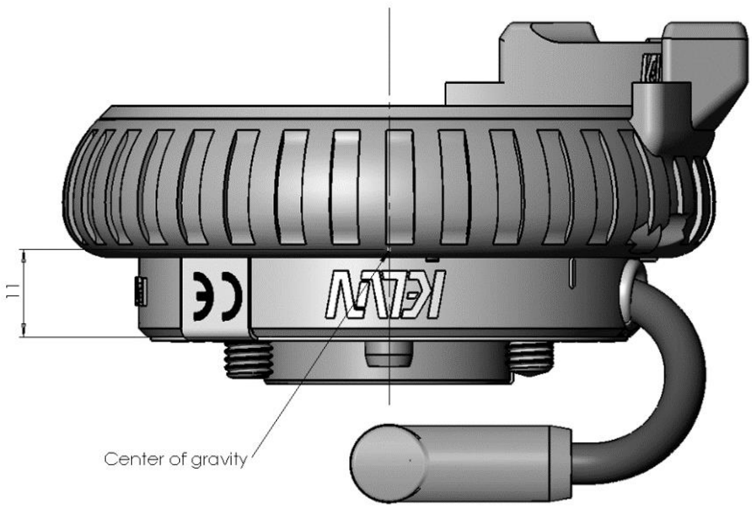
This weight is inclusive of the four M6x16 aluminum bolts, electric connector and pneumatic connector.

The tool changer will add 47 mm to the z-value for the position of a tool TCP. See chapter 5.12 for more information.

8.2 Master Plate

The weight of the master plate: 155 g
Inclusive of the four M6x16 aluminum socket head bolts for mounting.

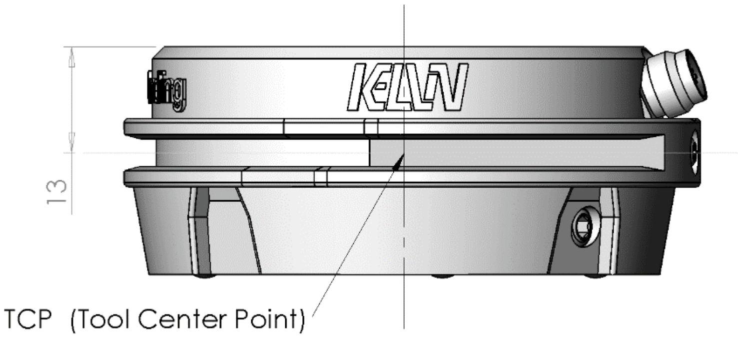
The center of gravity of the master plate is located 11 mm from the mounting flange.



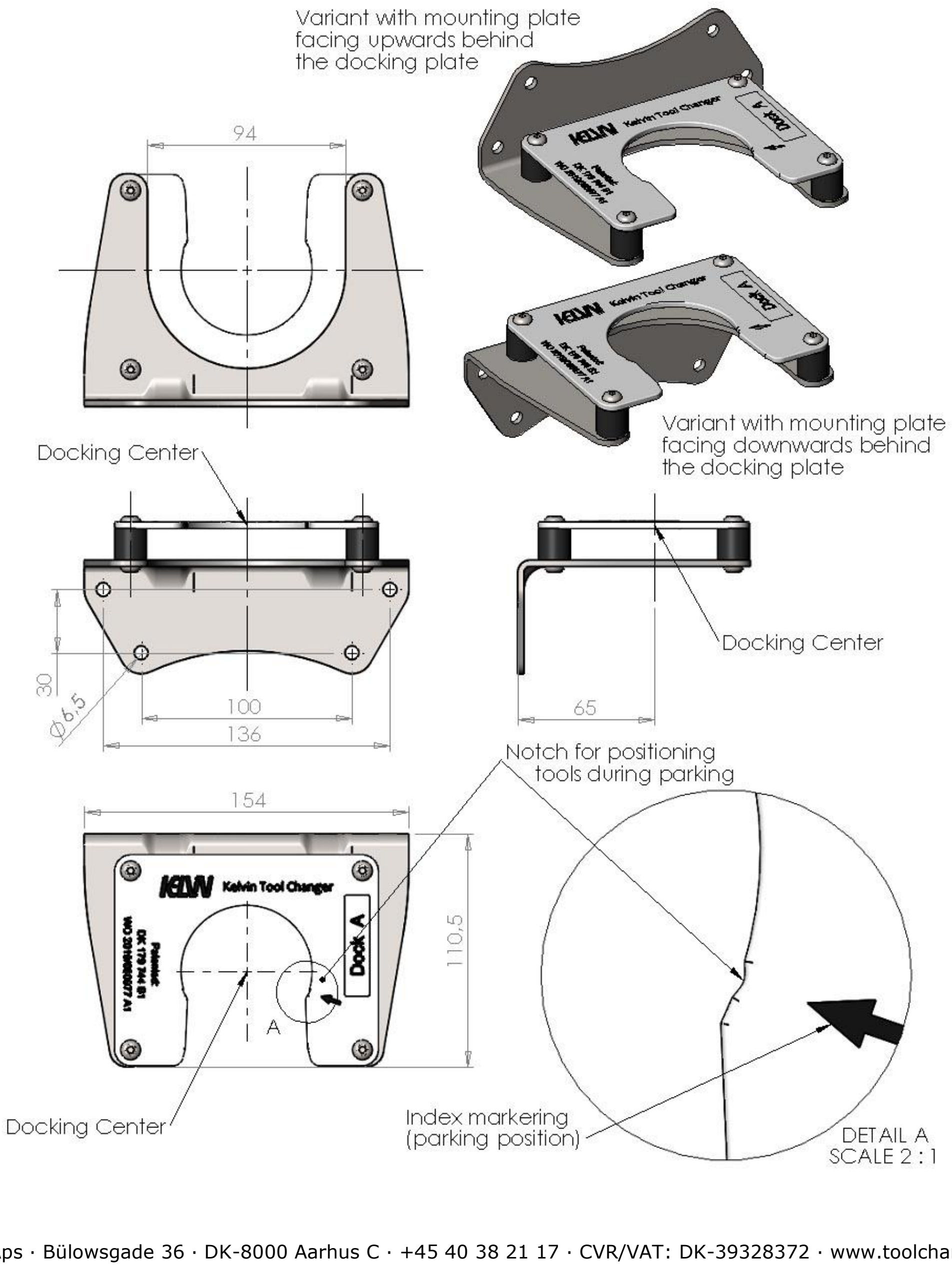
8.3 Tool Plate

Weight of the tool plate: 85 g (see chapter 5.12 for more information)

This is inclusive of electric and pneumatic connectors.



8.4 Docking Station

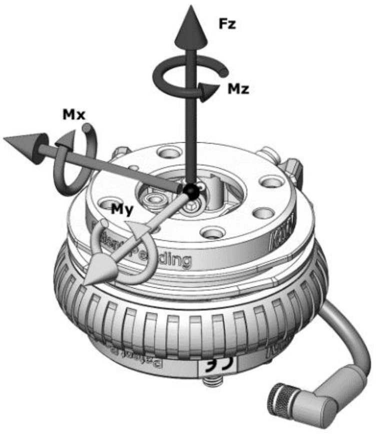


8.5 Load Capacity

The tool changer is only designed for lightweight operations.
The three-point constraint in the coupler has a very high repeatability but will only be able to handle low torque loads in some directions.

In the most critical direction, the tool changer cannot support a torque higher than 4 Nm at the connection inside the tool changer.

The maximum loads are listed here:



Fz	50 N
Mx	4 Nm
My	4 Nm
Mz	4 Nm

8.6 Weight

Weight of the master plate (with 4 aluminum mounting screws)	155 g
Weight of the tool plate (without mounting screws)	85 g
Tool changer (without tool mounting screws)	240 g

All weight values: ±5%

8.7 Environment

Temperature limits:	5° to 40° C
Humidity (relative humidity):	20% to 80% non-condensing
IP class:	IP54

8.8 Noise

The tool changer will not make a notable noise during tool pick-up or drop-off. The noise from the tool changer is far below 70 dB (A).

If the tool changer is opened with air under pressure in the pneumatic connector a short whistling sound can be heard. This is not normal and should be avoided by venting out the pneumatic lines before the tool changer is opened. See chapter 5.8.

8.9 Electrics

Supply voltage:	max 48V
Power consumption, tool changer	max 25 mW @24V
Power consumption, tool	max 15 W @24V
Current for tool	max 1000 mA

The power supply to the tool is established through a micro switch in the master plate. This micro switch will not establish the power supply to the tool until the locking ring is in the locked position.

8.10 Cleaning

First move the robot arm to the position for manual tool changing (Dock-M). This can be done by running the program: “Tool Service” (#41).

Do not touch the gold-plated pogo pin connectors inside the master plate. These pogo pins have direct contact to the robot controller.

Turn off the robot controller and remove the power cord from the controller.

Unmount the Kelvin cable connection from the tool socket on the robot arm. This will electrically disconnect the electric connector in the Kelvin Tool Changer from the robot controller.

Do not use compressed air, water jet or similar to clean the tool changer. Do not try to clean or rinse the tool changer with any solvent, soap or water. Do not try to lubricate the tool changer.

Whip over the 6 steel balls and the hook inside the master plate with a soft textile or paper napkin. This napkin can be soaked with isopropyl alcohol.

The tips of the pogo pins in the master plate and the gold-plated pads in the tool plate may be wiped over very carefully with the napkin.
Do not touch the pogo pins or the pads. Moist or grease from the finger may later cause dust to build up on the contact surfaces.

Replace the Kelvin cable on the tool socket and tighten the union nut on the plug.

8.11 Materials

The Kelvin Tool Changer is produced with restricted use of hazardous substances to protect the environment, as defined by the European RoHS directive 2011/65/EU.
These substances include mercury, cadmium, lead, chromium VI, polybrominated biphenyls and polybrominated diphenyl ethers.

RoHS

Pb lead-free

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9 Tool Changer Demo Program for Universal Robot

9.1 Program Scope

The Kelvin Tool Changer is delivered with a demonstration program on a USB stick. This demo program is only a program sample for demonstrating the functions of the tool changer.

This demo program will not run on a robot before the safety settings have been set up and values for tools, docking stations and workplace for the robot arm have been updated in the program.

From the start this program has many built-in stop points to prevent the program from operating with data that have not been set up for the actual robot installation. When the data have been updated these stop points can be suppressed and the robot can run the program.

The demo program is designed as a shell program that handles all tasks with the tool changer and the safety issues with the tool changer. User programs can be called subprograms. These user programs will typically only be a simple job with one tool.

This program can easily be reprogramed into a fully functioning program for a UR robot with a Kelvin Tool Changer.
4TECH Robotics ApS does not provide assistance with this program and the program can only be used at the responsibility of the integrator.

9.2 Program Structure

This chapter describes the sample program for using the tool changer on robots from Universal Robots.

The “Kelvin” program is designed as a program for running a UR robot with the Kelvin Tool Changer. The program is designed to handle all issues with switching between tools and to handle safety issues with the robot and these tools.
The Kelvin program is also a shell program that allows the user to call and run programs that do specific tasks with a tool.

The Kelvin demo program is here called the tool changer program when it is handling the switching between tools and the Kelvin shell program when it is handling the different user programs. But it is the same program. These are just different functions inside the Kelvin demo program.

User programs can be called from inside the Kelvin program. These programs are typically simple tasks that start and end with the tool in a specific handover position called “Ready”. From this “Ready” position the Kelvin program will handle the tool drop-off and pick-up functions. The shell function in the Kelvin program will allow the user to choose the next job for the robot.

When a user program is running the Kelvin shell will only intervene for safety reasons e.g. if the tool changer is manually opened during operations.

9.3 Planning the Robot Setup

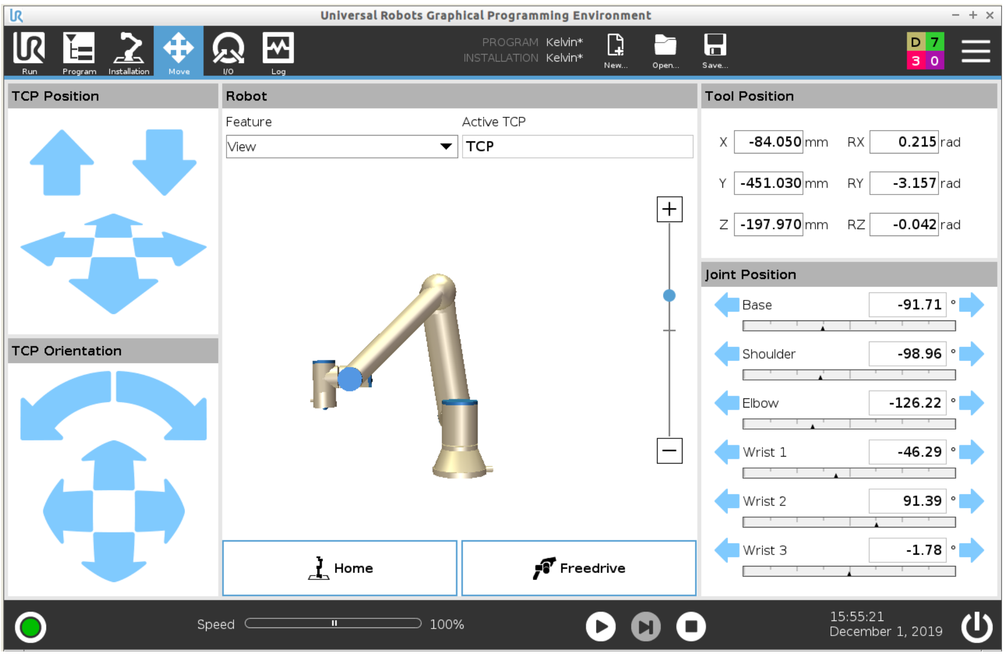
When a UR robot is set up with a tool changer some planning has to be done for running user programs and the tool changing operations.

First the docking stations must be placed where the robot arm can reach the position and have free space enough to drop off and pick up tools. It is recommended to place docking stations away from the user to reduce the risk. At the same time, it will be practical to have docking stations and the “Ready” position close to the position where the robot is going to work to minimize the time spent on changing tools.

It is recommended to take the robot manually through dock positions, “Ready” position and all paths used in the user program to make sure all joints in the robot arm are well within their limits.

It is recommended carefully to analyze the movement of the robot arm during user programs and docking programs to make sure all joints are inside their limits. This can be done by opening the “Move” window and with the robot arm in free move setting perform the movements planned for the programs. In the “Move” window it will be possible to see the values for all joints and make sure all joints will have enough space inside their limits.

Some combinations of work paths and docking operations might tend to wind up the robot arm and its joints. Often, another way to move the arm will prevent these problems.



With the "Move" tab opened and the robot in "Free Drive" mode it is possible to manually move the robot arm through the program steps. In the "Joint Position" window it is possible to follow values for all joints.

At the start of the program the robot arm will move to the start pose. The robot controller will always go for the shortest way to come to this pose and the robot arm may end up with the joints in different positions. At first this may not seem to be a problem but when the robot arm does more complex movements some joints may move out of their range or the robot arm may do some odd movements. Normally the robot arm will automatically move to the starting position without any problems but sometimes it need assistance from the user to find the right configurations with all joints in the right positions (Home Program).

9.4 Setting up the Kelvin Program

The "Kelvin" sample program is delivered on a memory stick together with the tool changer. This USB stick also contains some small sample programs that may be used as inspiration for user programs.

The easy way to install the Kelvin program on a robot is to place the USB stick in the teach pendant and load the Kelvin program from the USB stick (Kelvin.urp). The robot will ask for an installation file to use with this program. Try to use the "Kelvin.installation" file from the USB stick.

The installation file holds some specific information on each individual robot and sometimes a robot will not accept an installation file from a different robot. If the robot does not accept the installation file on the USB stick it is easy to create a new file for your robot. Open the "Installation" tab and go to "Load/Save". Here it is possible to create a new installation file. In this new file it is possible to set the safety configuration for the robot. Those "Save As …" and name this new file "Kelvin.installation" and save it to the home directory for the robot.

The installation file holds information on TCP and if a new installation file is generated TCP_1 must be set up for the tool changer.
Under the "Installation" tab open "TCP Configuration" and create (or edit) a new TCP_1: (X:0 Y:0 Z: 34 RX:0 RY:0 RZ:0 Payload: 0,3). See chapter 9.5 for more information.

When the Kelvin program starts, save the program to the home directory on the robot. Make sure the current installation file is the "Kelvin.installation" and that it is also located in the home directory on the robot.

Before the Kelvin program is ready to run on a UR robot some parameters must be set up in the Kelvin program. Positions of docking stations, “Ready” positions and some points to help the robot arm to move safely between positions all have to be set up before the Kelvin program can start doing some work with the tool changer.

In the demo program all information on tools, docking stations, tool IDs, etc. are coded into the program as fixed values.
From the start the program only has simple default values. These have to be updated with real data from the new robot installation.
To prevent running a part of the program that has not been set up with proper data, the program has some built-in popups that stop the program. When values are updated in the program these stop popups can be removed or suppressed. See chapter 3.9 for more information.

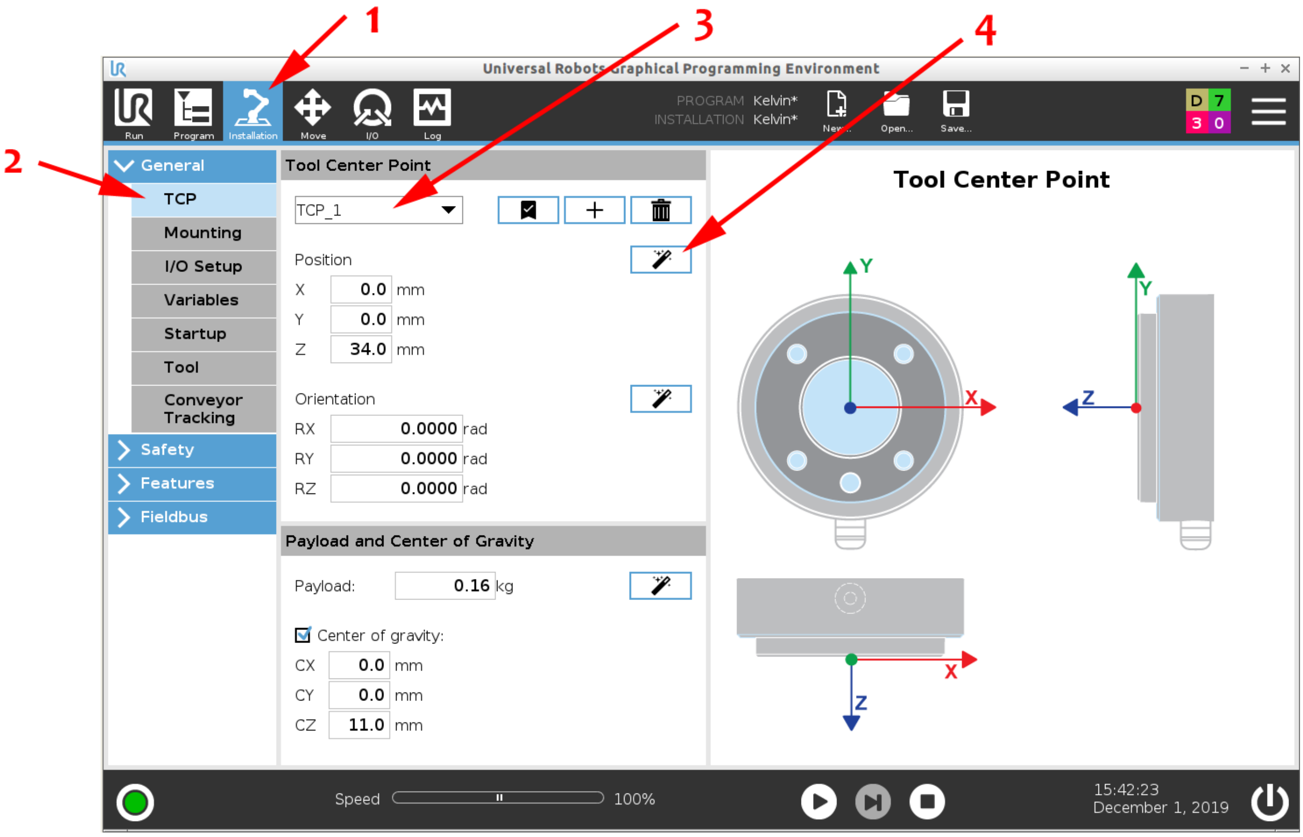
Some data for e.g. moving the robot arm between docking stations could also be set up as simple waypoints in the program. But waypoints will not always survive when the program is copied to and from controller. Reinstalling from a backup will typically lose all waypoints. Hard coded values will survive these backup operations and it is recommended to hard code the data for waypoints into the Kelvin program.

Here follow 8 steps for setting up the robot with data for the Kelvin program. It is only necessary to set up data for the functions or equipment to be used. If e.g. Dock-D is not present, just leave it with the default values. The built-in stop popup will prevent the program from running these parts of the Kelvin demo program.

9.5 Tool Center Point

First the Tool Center Point (TCP) must be set up for the tool changer and for the tools to be used with the tool changer. Programs will use this point for all movements of the robot arm and the tools.

Open the "Installation" tab (1) and you will find a menu point (2) for setting up TCP (3).



The default TCP for the robot is set to the center of the mounting flange on the robot arm (0,0,0).

TCP-1 is located in the center of the tool changer and TCP-1 is used for the docking operations. The value for TCP-1 has already been set up in the demo program. TCP-1: (0,0,34).
More information on TCP-1 for Kelvin tool changer in chapter 5.12.

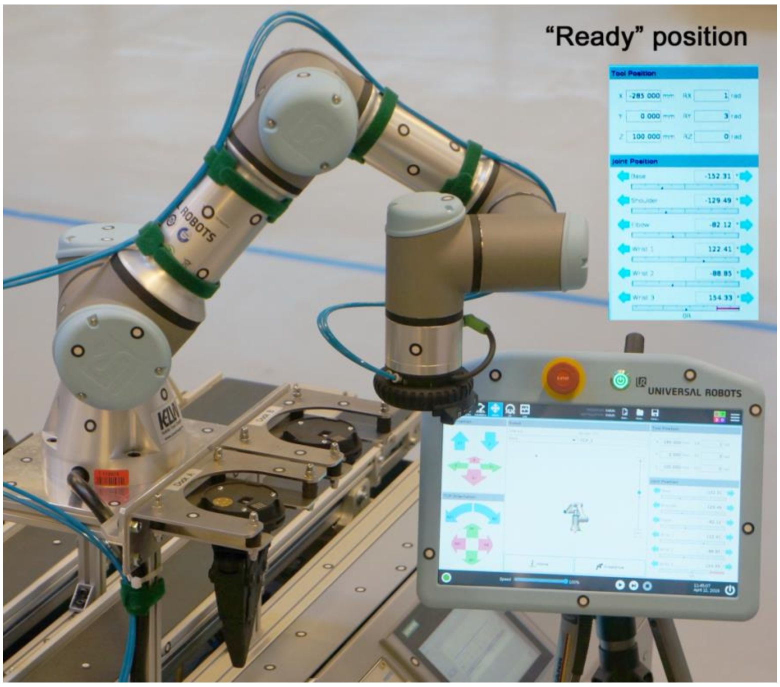
TCP-2 to TCP-10 have been set up with default values and can be updated with information for the tools to be used with the tool changer. More TCPs can be defined if needed.

The UR controller has a program that allows the robot to find the TCP for a tool by holding the tool in four different positions. Click the magic wand (#4 in the screen dump above) to start the program.

9.6 "Ready" Position

The Kelvin program is set up with a fixed pose for the shift between the docking operations done by the Kelvin program and operations done by user programs. This position is called "Ready" and is a kind of exchange position between the tool changer operations and the user programs for the robot.

This "Ready" position should be set up in a position where it would be natural for the work process to have this shift between the Kelvin program (drop-off and pick-up tools) and the user programs where the robot is doing tasks with different tools.



Here the "Ready" position is set up in front of the two docking stations.

9.7 Docking Stations

Positions for docking stations have to be set up for the Kelvin program to be able to pick up and drop off tools in these docks.

Only the information on the center position (pose) needs to be set up for the docking station. The program will perform all movements relative to this pose.

The Kelvin demo program has a series of predefined docking stations that can be updated with position information from a specific robot installation.

See chapter 7 for a full description on how to set up and adjust docking stations. A more technical description of the docking sequence can be found in chapter 11.

9.8 Transit

When the robot arm has to move between different fixed positions for docking stations and the "Ready" position it will be necessary to make sure that the robot arm and tools do not collide with obstacles.
To guide the robot arm safely between these positions a set of fixed waypoints has to be defined.

In the Kelvin program these waypoints are defined with default values but with a new installation with new positions for docking stations all waypoints have to be updated.

Move the robot arm in free mode through a safe path between these positions and copy the value for relevant poses to these waypoints in the program.

From the start all these transit moves are set up with a "stop popup". These popups can later be removed when a path has been updated. By keeping the popups in paths that have not been updated the robot can be prevented from following one of these paths by mistake.

9.9 Dock-M

Not only must the positions of the physical docking stations be set up. The Kelvin program also has a docking station for manual changing of tools. This is the Dock-M.

Robot arm at Dock-M

The robot arm will move to this position when the user has to change the tool manually. It is recommended to choose this position so that it will be easy and safe for the user to access the tool changer and the tool during the manual operation.

It is recommended to set the "Dock-M" with the tool in a vertical position pointing upwards. This will prevent the tools from falling out of the tool changer when the lock is released

When a tool is manually mounted at Dock-M the Kelvin program will detect the tool ID and wait for the operator to approve the use of this tool.

The Kelvin program will only allow the operator to release the tool when the robot arm is stopped at Dock-M. If the tool is released before the robot arm is at a standstill at Dock-M the program will stop the program and all movement of the robot arm.

9.10 Tool ID

Tool plates have different built-in ID numbers. These IDs are checked by the program to verify what tool is connected to the robot arm. When setting up a robot installation it must be set up which tool ID the program has to check for in different situations.

As default the program will check the tool ID when a tool is picked up from a docking station. It will check it again before a tool is parked in a docking station. More info on this stop program in chapter 3.9.

The demo program will also continuously check that the tool is not released during operation. The demo program will only allow tools to be released in docking stations or when the robot arm is at Dock-M and it will ask the user to change tools. See also chapter 3.9.

See chapters 5.7 and 6.6 for more information on tool ID.

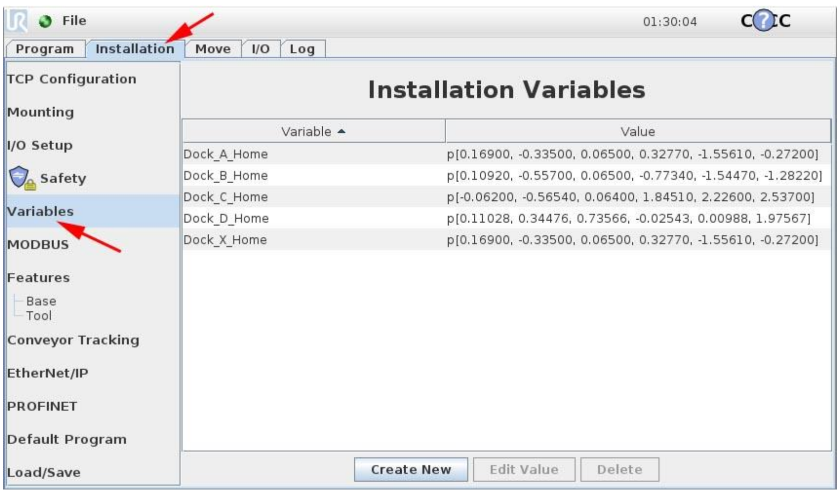
9.11 Backup

Prevent losing the setup data for the tool changer by backing up the Kelvin program. This can be done from the “Save” tab.

The Kelvin program has a service program for adjusting docking stations. This program can also reinstall a backup value for a docking station. This will only be possible after the data for the dock have been saved to the backup. Once a docking station have been installed and adjusted it is recommended to save the data for the docking station.

The “Home” pose for each docking station must be hardcoded into the program. Each docking station has a code line for saving this information.

A simple and quick way to save the information on the docking stations is to open “Installations” and “Variables” and take a photo of the data.



9.12 Kelvin Shell Program

At start-up the Kelvin program will check the status of the robot and move the robot arm to the "Ready" position.

Next it will ask the user which subprogram to run. Each subprogram in the Kelvin shell program has a number and when one job is finished the user can choose what to do next by entering the number for the next task.

The Kelvin program has some service programs, e.g. for adjusting docking stations, backing up dock information, setting the language, etc. See chapters 10.8 and 10.9.

9.13 User Programs

The user can set up more programs in the Kelvin program. A series of empty program numbers have been set up and are ready to use from the task menu.

It is recommended to program tasks for the robot as small independent programs and call these programs as subprograms from the Kelvin shell program. User programs can be programed, tested and optimized as independent programs.

A typical user program can be a path for a glue dispenser. The path can be programed and tested with the glue dispenser. The lead-in and lead-out for the glue path must be extended to start and end close to the "Ready" position. This program can then be called from the Kelvin program. In the Kelvin program a menu number can be set up for this glue operation. First step will be to change to the glue dispenser. Then run the user program for dispensing the glue and finally the glue dispenser can be placed back in the docking station.

The user programs can be linked with the original program and all changes made to the program from within the Kelvin program will be saved in the independent program.

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10 Code Structure

10.1 Kelvin Program Design

The Kelvin program is designed to handle operations with the tool changer and to act as a shell for executing programs requested by the user.

All operations with the tool changer are programed as small programs that all do a simple task like moving from one docking station to another. These subprograms are grouped into subfunctions that can do more complex tasks such as changing from one tool to another. Subfunctions in their turn can be combined to programs.

The program asks the user which program he wants to run. The input is saved as a "Kelvin Action" value and used to activate the requested program.

The main part of the Kelvin program is built as a loop with steps containing programs. Each of these steps starts with an "if-then" statement that checks the value of the "Kelvin Action" input. If the value of the Kelvin action satisfies the if-then check the program in this step will be executed.

When the program in a step comes to an end the Kelvin program will ask the user for the next task. The user input will go back into the main loop and the program matching the input will be executed.
Last step in the loop will check for non-valid input. All valid inputs must be listed in this step.

The Kelvin program will keep executing programs until the user runs the shutdown program by inputting "0".

10.2 Code Structure

The code for the Kelvin program consists of four main parts:

- First a "BeforeStart" section with general information and values used by the program. The information and data are arranged in folders and information on values can be found in the folders. Some values such as the positions of docking stations also have backup values and default values.

- Next the program part, which mainly consists of a "StartUp" and a main loop. Most of the activity in the robot program will be in this loop. The loop consists of many if-then sentences that use the user input to find the code to run. Most of the if-then sentences are not used but free for the user to set up with programs.

- Third part is a folder with many subfunctions. Each of these subfunctions will do a specific task like switching from one tool to another. These subfunctions are not executed in this folder but can be copy-pasted into the main program.

- Fourth part of the program is a long list of subprograms. These are typically small programs performing a simple task like moving the robot arm from one position to another. Theses subprograms are used multiple times in the program and save the programmer from programing the same code over and over again. Independent programs that are called from the Kelvin program as subprograms will also appear in these sections.

10.3 "Kelvin_Action"

The number input used to choose program is a value called "Kelvin Action". This value will be used by the "if-then" sentences in the program to decide which program code to execute.
At start-up "Kelvin Action" is set to "1" and the initializing program is automatically run as the first program.

10.4 Closing down

If the "Kelvin Action" is set to "0" the Kelvin program will close down. The last if-then sentence will look for "0" and shut down the program. This sentence also checks if the user input is valid or not. If more if-then sentences are added to the program the number for these new programs must be added to the check list.

After the Kelvin program has been closed down the robot can be used for running other programs but it will not be possible to use the automatic tool changer function or to check tool ID. Tools can still be changed by operating the tool changer manually.

The Kelvin program can be restarted by running the program "Kelvin.urp".

10.5 Subfunctions

The subfunctions are typically used for building the part of a program that relates to the changing between tools. A subfunction is built from a set of subprograms and typically placed in a folder.

Only subprograms can be called within the program. Subfunctions cannot be called but must be copied into the program where they are needed. Copies of the subfunctions are located in a folder named "SubFunctions". From here complete subfunctions can be copy/pasted into the program. Subprograms are only an easy way to place a large group of subprograms into the program at once.

A subfunction could be a small program that switches from one tool to another. This subfunction will not only drop off the first tool, move to the next docking station and pick up the tool. It will also check the tool ID before parking the first tool, check that the hook is in the fully open position before the master plate connects to the tool plate in the next docking station, check that the hook is in the locked position, check the tool ID for the new tool, etc.

Subfunctions shall not run in the subfunction folder. To prevent the robot program from running these programs by accident some halt commands surround the subfunction folder.

10.6 Thread Programs

Between subfunctions and subprograms some ”Thread” programs are placed. These are small pieces of code that run independently of the robot program. These programs are typically used to react on sensor input. One of the thread programs is used to continuous checking that the tool changer is not being opened during operation.

If the robot with the Kelvin Tool Changer is used in a collaborative setup it is strongly recommended to have this thread activated.

“Thread_1” continuously checks if the tool changer is locked during operation. The tool changer can always be manually unlocked by the operator. If this is done at a time that is allowed in the program the robot shall stop all operations. An unlocked tool may result in potentially dangerous situations for operator, robot and tools. See chapter 3.9.

During planned operations of the tool changer a “ToolFree” value can be set high to allow the tool to be disconnected from the tool changer.
In the program this value is automatically set high right before a tool drop-off and again set low right after a tool pick-up.

The Thread_1 string will stop the robot if ToolFree is not equal to 1 or if no tool ID is detected. A tool ID is detected when AI1>4.6V @24V.

“Thread_2” translates the “Pneu-A” and “Pneu-B” into control settings for pneumatic valves to open/close the air supply to the tool changer. Under “Pneumatics” valves connected to the controller can be set up with output ports in the robot controller.

The “Thread_3” program is set up to send control input to a pneumatic pressure regulator. In the main program the user can set the “P_Pneu” variable to the pneumatic pressure he wants, e.g. 5 bar. The thread program will then translate this value into a signal for the pressure regulator.

10.7 Subprograms

The Kelvin program has many small subprograms. Each of these subprograms will do a specific task e.g. move to a docking station, check for a tool ID or move between two docking stations. The subprograms are combined to subfunctions and each subfunction will do a more complex task.

10.8 Kelvin Programs

When the Kelvin program is running the user can choose between different programs or tasks by entering a Kelvin-Action number. Some of these programs are common for all robots with the tool changer, others are specific for a robot installation and many programs are free for the user to set up with their own programs.

1: Initializing Procedure

A self-test program that is automatically executed at the start of the Kelvin program. This program can also be used to check that the robot is ready for operation.

2-9: Free

These programs are free for the user to add programs for the robot. Code sentences for performing special tasks can be copy/pasted from the demo programs and supplied with call to independent programs. This could e.g. be a path for a glue dispenser.

40: Info

Information on Kelvin Tool Changer, program, etc.

41: Tool Service

A series of programs helping the user to handle tools.
The programs can pick up a tool from a docking station and bring it to the manual dock station or bring a tool from the manual dock to a docking station. This is useful if dock stations are placed well away from the user.

42: Dock Set-up and Adjustment

A service program for setting up and adjusting docking stations. The user is guided through a setup process that allows him to adjust the position of a docking station and test the tool drop-off and pick-up process with the new position. Finally, the new position for a docking station can be saved and used in the future by the Kelvin program.

43: BackUp

This program allows the user to save setup data for the positions for docking stations, typically before adjusting docking stations. The information in the backup will NOT be saved permanently. The information coded into the BeforeStart section under the different docking stations for the data to be used after a restart.

44: Reload from BackUp

This program allows the user to load data from the backup. This can be useful if the position data for a docking station have been corrupted or lost.

45: Pause

This program simply gives the user a 10 second pause in the program. This time can be used to switch the background window to “Move” or “I/0”. With these windows in the background the user can e.g. follow the live data for the movements of the robot arm or the in- and output from the robot controller.

46: Language

This program allows the user to choose the language for the most common popup messages. Default language is English but Danish, German, French and Spanish are available as well.

77: Quick Menu

This program only shows a single popup with a short list of programs. Users may put their favorite programs on this list.

88: Full Menu

This program shows a series of popups listing all programs.

99: Short Menu

This program shows no list of programs but allows the user to enter a program number directly, saving time for the experienced user.

0: End Program

This program will shut down the Kelvin program. The values that have been changed or updated are saved as Installations Variables and will be reloaded next time the program is started.

10.9 Demo User programs

The Kelvin demo program has some demonstration programs. These are only samples to show how user programs can be called from the Kelvin program. These programs can be changed or removed.

Programs marked with "Free" hold no programs but are ready for the user to set up their own programs. Demonstration programs have been set up to show how user programs can be coded into the Kelvin demonstration program.

10: Demo: Pick up and Drop off Tool-A
This program only picks up and drops off tool A for a demonstration of the basic tool changer functions.

11: Demo: Pick up and Drop off Tool-B
Same as program #10 but with tool B.

12: Demo: Pick up and Drop off Tool-C
Same as program #10 but with tool C.

13: Cycle tool A, B and C
This program will shift between the three tools in a loop.
This program can easily be edited with programs for each tool and act as a program for the robot.

14: Demo: with Manual Tool Changer
The Kelvin program will allow the operator to manually mount a tool on the robot arm.

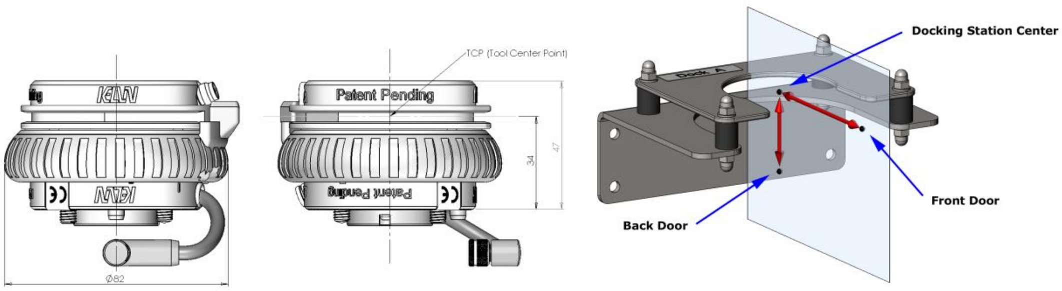
11 Docking Sequence

This chapter is a general description of the docking sequence.
The Kelvin demo program is for robots from Universal Robots but it is also possible to use the Kelvin Tool Changer on other robots.
For programing other robots this chapter has a detailed description of the cool changing process.

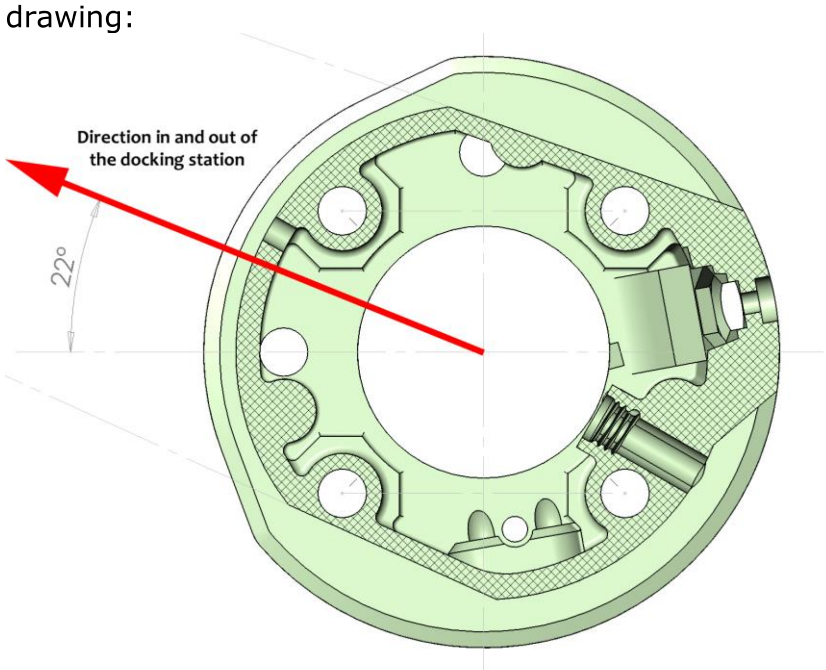
11.1 Docking Sequence

The following description gives systematic step-by-step information on the docking sequence. It describes all the movements and positions the robot arm will follow during a docking sequence.

The reference point for the tool changer will be the tool changer TCP and the reference point for the docking station will be the docking center.



The drop-off sequence starts with the tool changer TCP at the “Front Door”, the tool changer being aligned with the docking station.
The direction for the tool changer to enter the docking station comes from the geometry of the tool plate. Depending on how the master plate is mounted on the robot arm the direction can be found from this drawing:



The direction into the dock is off by 22° relative to the mounting holes.

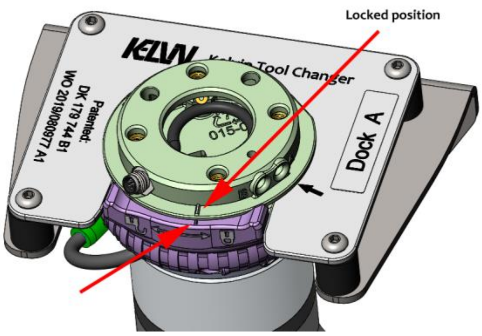
First the tool changer will move into the docking plate by a straight line through the center of the docking plate. The tool changer will overshoot the dock center by 1 mm and stop at a position called "Start".
This overshooting will flex the rubber mounts and make sure that the master plate is fully inserted into the dock plate.
The distance from "Front Door" to docking center is 90 mm and the distance from "Front Door" to the "Start" position is then 91 mm

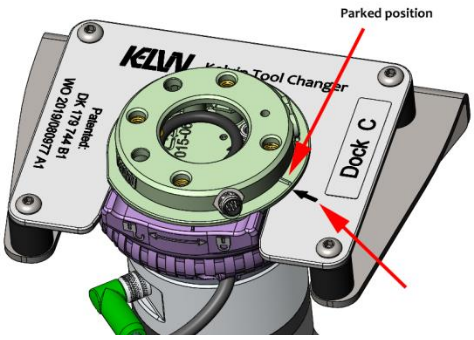
When the tool changer is in this position there should be a small gap between the "shoulders" on the locking ring and the cut out in the docking plate. This gap should be the same for each side of the shoulders.

Next the tool changer will make a combined rotation and displacement. The rotation will cause the locking ring to release the locking mechanism. The rotation is 67° which is actually 4° more than the locking ring is able to move. This overturning will flex the rubber mounts and turn the docking plate relative to the mounting plate for the docking station. This overturning is necessary to make sure the lock is at the fully open position.

The center of the tool changer will also move back to the center of the dock plate. This position is named "Unlock". The movement is 1 mm.

Next the tool changer will rotate back to the parking position for the tool plate. This is not only to undo the overturning but it will actually rotate a little further back to make the locking ring free of the docking plate. At this position the spring-loaded index ball in the dock plate will click into the small notch in the docking plate and keep the tool in the right position when it is parked in the docking station. This position is called "Park". This rotation is 4° back from the "Unlock" position and 63° from the "Start" position.





The marking on the tool plate should match the marking on the docking plate. On the early version of the docking plate this marking is only a punch mark and not a laser-engraved arrow as shown in the illustration.

Next the robot arm will move the master plate out of the tool plate and stop at the "Back Door" position. This is just a straight 45 mm movement.

The robot arm, with the master plate, is now at the "Back Door" position and has finished the tool drop-off sequence.

The pick-up sequence starts again from this position.

First the master plate moves from the "Back Door" position into the "Park" position. The funnel shape of the master plate will help the tool plate to catch the master plate and any misalignment will just flex the rubber mounts.

Next the tool changer rotates to activate the locking mechanism. This rotation will overshoot by **5°** to make sure the lock will get into the locked position. The torque required to bring the lock in the locked position is relatively high which is why the locking overshoot is larger than the unlocking overshooting. Again, this overshooting will flex the rubber mount. The rotation from the "Park" position to this "Locking" position is 68°.

Next the tool changer will rotate back to release the locking ring from the docking plate. This position is called "Center" and here the tool plate TCP is actually in the center of the docking station. This rotation will be 5° and there should again be two small gaps between the shoulder and the cut out in the docking plate.

Finally, the tool changer with the tool can move out to the "Front Door" position and the pick-up sequence is finished.
This final movement is 90 mm.

11.2 Safety Check

For safety reasons the robot program must do some status check during the docking operations. This is done by checking the voltage level on the tool changer feedback signal.

To prevent the tool from being released during operation "Thread_1" will continuously check that the tool is locked. To allow the tool to be released "ToolFree" must be set to "1".

Before a tool is parked in a dock the program must ensure that the tool actually belongs to this docking station.
When the robot arm is at the "Front Door" and ready to start a tool drop-off session the program must first check that the tool ID of the tool it is about to park matches that docking station.

Before the robot picks up a tool the program must check that the hook is in the fully open position and that the tool changer is ready for the docking process. When the robot arm is at the "Back Door" position the program must check that the hook is in the fully open position.

After the tool changer is connected to a tool the program must both check that the hook is in the locked position and that the tool has the right tool ID. See chapters 5.7 and 6.6.

When the robot arm is at the "Front Door" position, after the pick-up session, the program can both check for hook position and read the tool ID. These two checks can actually be done only by checking the tool ID. If the lock is not in the locked position the check for tool ID will not return a valid value. Even a tool without a tool ID will not return a valid ID-0 value if the hook is not in the locked position.

If the hook is not in the locked position the program may first ask the user to manually turn the locking ring into the locked position and then check the hook position again. This safety check will never allow the program to continue without the hook in the locked position.

To prevent the tool from being released during operation the "Thread_1" must again be activated by setting the value to "0".

12 Maintenance and Repair

12.1 Maintenance

All maintenance, calibration and repair work must be done according to the latest versions of service manuals and comply with all safety instructions in this manual.

It is recommended only to allow authorized system integrators, or 4Tech Robotics ApS, to perform repairs to the master plate in the Kelvin Tool Changer.

Parts or components can only be returned to 4Tech Robotics ApS by agreement and shall be returned according to the service manual.

12.2 Safety Instructions

Check the earth connection before re-powering the system.
If the tool changer is damaged e.g. as the result of a collision the tool changer must be sent back for repair and adjustment. Do not try to repair or fix the tool changer.

Do not open the back plate on the master plate. There is a high risk that components will fall out or get misplaced. There are no serviceable parts inside the master plate.

12.3 Cleaning Electric Contacts

Cleaning the gold-plated connectors in the master plate.

Power off the robot and disconnect the connector from the tool socket on the robot arm. Use soft paper tissue soaked with isopropyl alcohol to wipe over the connectors.
The 3M cleaning pads in the box may be used for this after the tool changer is installed on the robot arm.

12.4 Maintenance Schedule

Once a year the safety functions for the robot and the tool changer must be tested to verify the function.
This test must be well-planned and may only be done by skilled service personnel.

Testing the Stop Function for the Tool Changer:
Mount an empty tool plate on the robot arm. Set up a program that moves the robot arm at very low speed after the manual tool change. While the robot arm is moving, manually release the locking ring on the tool changer. As soon as the locking ring is turned away from the fully

locked position the robot program shall halt the program and stop the movement of the robot arm. Turning the locking ring back into the locked position shall not allow the program to continue.

Testing the Capability of Recognizing the Tool ID:
At the manual docking station different tools can be mounted on the robot arm using the program for manually changing the tool. When a tool is mounted the program will read the ID for the tool and ask the operator to confirm the use of the tool. When testing with different tools the program must read the right tool ID every time.

Testing the Position of the Dock Center for each Docking Station:
Let the robot arm drop off and pick up a tool from a docking station. During the docking operation observe how the dock plate is moving in the rubber mounts. The rubber mounts should only be flexing when the robot arm overturns the tool changer to make sure the locking ring is turned into the locked position. The dock plate may flex again when the tool changer is turning the locking ring out of the locked position. When the tool plate slides into and out of the docking plate there should not be any flexing of the docking plate. If the docking plate is flexing in these situations the center position for this docking station need to be optimized. This can be done by running the program for setting up docking stations (program #42). This program can also be used to examine the docking operation.

Testing the Clearance of the Rocking Ring:
When a tool is connected to the tool changer and the locking ring is in the locked position there shall be room for a small movement of the locking ring. The movement of the locking ring in the locked position shall be at least ±1 mm but not more than ±2 mm at the marking on the tool plate. If the free movement of the locking ring is not within these tolerances the clearance in the locking ring must be adjusted. See chapter 5.14.

Adjusting Hold-down Force:
The hold-down force done by the hook on the tool plate must be strong enough to keep contact between the master plate and the tool plate while the robot is operating.
If the hold-down force is not strong enough the tool plate will move in the contact between the steel balls in the Kelvin constraint. The tool changer will not drop the tool but this movement between the steel balls will wear the surfaces of the steel balls.
Test the hold-down force by manually turning the locking ring in and out of the locked position. The torque to lock the tool changer should be around 1 Nm.
If a tool plate is not locked with the decided force the conical dowel pin in the tool plate can be adjusted. See chapter 5.11.

13 Troubleshooting Guide

Hook not in Locked Position:
The program may stop right after a pick-up operation with a warning that the tool changer is not in the locked position.
Check that the power supply to the tool is on. Without power supply to the tool changer it will not be possible to verify that the tool changer is locked and safe to use.
It may also be that the locking ring did not move into the locked position during the pick-up operation. It is possible to let the tool changer turn a little extra to force the locking ring into the self-locking position. This is done by changing the program for the locking operation to use a higher value for the rotation of the tool changer in the docking plate. A series of values for this rotation is defined with names like "DeltaLocking5". If the locking ring needs a little more to go into the locking position upgrade to the next value from this series of overturning values. A series of assignments for each docking station has been set up with different values of DeltaLocking. The one to be used is not suppressed.

Wrong Tool ID or Tool ID not Found:
If the program does not find a tool ID or finds a different ID than expected the program will stop. For safety reasons the program will only accept to work with tools set up in the program. If a tool has been placed in the wrong docking station, the program will typically stop with this warning.

Docking Operation is Noisy:
The physical position of the docking station mismatches with the information in the program. The docking station may have been hit and moved out of position. The position of the docking station has to be set up again or adjusted. Run program #42 to update the dock position.

Air Leaking from Tool Changer:
Air will leak from the tool changer if a sealing O-ring in the master plate is missing or misplaced. Replace the missing O-ring with a spare O-ring. If the tool changer is opened with pressure on the airlines the O-rings may be misplaced or even blown out of the connector housing.
Make sure the air pressure is released by the pneumatic valves before the tool changer is opened

Tool Changer not Connecting to a Tool Placed in a Docking Station:
If a tool is not in the right position in the docking station the master plate will not be able to connect to this tool. The tool must be in the locked position in the dock. The marking on the tool plate must be aligned with the arrow marking on the tool plate. At this point the spring-loaded indexing ball in the tool plate will also click into the notch in the tool plate.

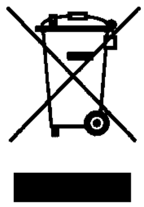
"Thread_1" Error Popup:
If the robot stops with a popup declaring that: "Hook is not in locked position!" the Thread_1 program stop has been activated. This stop popup is labeled with "Thread_1". See chapter 3.9 for more information.

Error Popup: "Waypoint Data Need Update"
If the robot program runs a part of the program code that has not been set up with proper waypoint information this popup will stop the program.
All waypoint stop-popups are labeled with a unique number that will make it easier to find the stop-popup that has been activated in the program. More info in chapter 3.9.

14 Disposals and Environment

14.1 Disposal of the Devices

The parts in the tool changer shall not be disposed with household waste. Please hand them over to any collection point for electric devices in your community or district.



The Kelvin Tool Changer must be disposed of in accordance with the applicable national laws, regulations and standards.

14.2 Disposal of Packaging

Packaging material shall be recycled. Please do not dispose with household waste and act according to the local disposal regulations.

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15 Intellectual Properties

15.1 Patent

The Kelvin Tool Changer is patented under the Danish patent:
DK 2017 00599 B1
https://onlineweb.dkpto.dk/ef/2019/5/119585840.pdf

The Kelvin tool changer is patent-pending under PTC as:
WO 2019/080977 A1
https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2019080977&recNum=1&office=&queryString=FP%3A%284tech%29&prevFilter=&sortOption=Pub+Date+Desc&maxRec=82

Danish patent PTC patent pending

The patent covers master plate, tool plate and the docking station.

Any violations of the patent will be prosecuted.

15.2 Trademark

15.3 Design

15.4 Software

The program for the Kelvin Tool Changer is a free demonstration program and can be used or changed as desired.

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16 Warranties

16.1 Product Warranty

Without prejudice to any claim the user (customer) may have in relation to the dealer or retailer, the customer shall be granted a manufacturer's Warranty under the conditions set out below:

In the case of new devices and their components exhibiting defects resulting from manufacturing and/or material faults within 12 months of entry into service (maximum 15 months from shipment), 4TECH Robotics ApS shall provide the necessary spare parts, while the user (customer) shall provide working hours to replace the spare parts, either replace the part with another part reflecting the current state of the art, or repair the said part. This Warranty shall be invalid if the device defect is attributable to improper treatment and/or failure to comply with information contained in the user guides. This Warranty shall not apply to or extend to services performed by the authorized dealer or the customer themselves (e.g. installation, configuration, software downloads). The purchase receipt, together with the date of purchase, shall be required as evidence for invoking the Warranty. Claims under the Warranty must be submitted within two months of the Warranty default becoming evident. Ownership of devices or components replaced by and returned to 4TECH Robotics ApS shall vest in 4TECH Robotics ApS. Any other claims resulting from or in connection with the device shall be excluded from this Warranty. Nothing in this Warranty shall attempt to limit or exclude neither a customer's statutory rights nor the manufacturer's liability for death or personal injury resulting from its negligence. The duration of the Warranty shall not be extended by services rendered under the terms of the Warranty. Insofar as no Warranty default exists, 4TECH Robotics ApS reserves the right to charge the customer for replacement or repair. The above provisions do not imply a change in the burden of proof to the detriment of the customer.
In case of a device exhibiting defects, 4TECH Robotics ApS shall not be liable for any indirect, incidental, special or consequential damages, including but not limited to, lost profits, loss of use, loss of production or damage to other production equipment.
In case of a device exhibiting defects, 4TECH Robotics ApS shall not cover any consequential damage or loss, such as loss of production or damage to other production equipment.

16.2 Disclaimer

4TECH Robotics ApS continues to improve reliability and performance of its products, and therefore reserves the right to upgrade the product without prior warning. 4TECH Robotics ApS takes every care that the contents of this manual are precise and correct, but accepts no responsibility for any errors or missing information.
Specifications are periodically reviewed and may change without notice.

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17 Declarations and Certificates

17.1 CE/EU Declaration of Incorporation

Declaration of incorporation for a partly completed machine follows in English and Danish on the next two pages.

Kelvin Tool Changer

Declaration of Incorporation for a partly Completed Machine

According to European Directive 2006/42/EC annex II B

The manufacturer of partly completed machinery:

Name: 4TECH Robotics ApS
Address: Bülowsgade 36
City: DK-8000 Aarhus C
Country: Denmark

Declares that this product:

Type: Kelvin Tool Changer
Serial number: 001- 999

Is partly completed machinery is manufactured according to:

2014/30/EC EMC-directive

This partly completed machinery complies with all essential safety and health requirements according to Directive 2006/42/EC, annex I:
1.1.2, 1.1.3, 1.1.4, 1.2.1, 1.2.3, 1.2.4.3, 1.2.6, 1.3.2, 1.3.3, 1.3.4, 1.3.7, 1.3.8.1, 1.5.2, 1.5.4, 1.5.8, 1.5.10, 1.5.11, 1.6.1, 1.6.3, 1.7.3, 1.7.4.1, 1.7.4.2.

The manufacturer declares that drafted special technical documentation for this partly completed machinery is in accordance with the 2006/42/EC Machine Directive annex VII, part B.

The manufacturer undertakes to hand over the special technical documentation to the market surveillance authority on a reasoned request.

Representatives of the creation of the technical documentation:

Name: 4TECH Robotics ApS
Address: Bülowsgade 36
City: DK-8000 Aarhus C

Commissioning of the partly completed machinery is not allowed as long as the partly completed machinery is installed in a machine or assembled into a machine with other parts that have been declared in accordance with the provisions of 2006/42 / EC Machine Directive including risk assessment, manual and EC declaration of conformity acc. annex II A.

Henning Forbech
CEO, Founder & Owner
Aarhus, February 5th, 2020

Inkorporeringserklæring for delmaskine

2006/42/EF bilag II B

Fabrikant af delmaskine:

Navn:	4TECH Robotics ApS
Adresse:	Bülowsgade 36
Postnr. og by:	DK-8000 Aarhus C

Erklærer hermed at delmaskine type:

- Kelvin Tool Changer
  Serial number: 001- 999

Delmaskinen er fremstillet i overensstemmelse med følgende EF-direktiver:

- 2014/30/EU EMC-direktivet

Denne delmaskine overholder følgende væsentlige sikkerheds- og sundhedskrav jf. 2006/42/EF Maskindirektivets bilag I: 1.1.2, 1.1.3, 1.1.4, 1.2.1, 1.2.3, 1.2.4.3, 1.2.6, 1.3.2, 1.3.3, 1.3.4, 1.3.7, 1.3.8.1, 1.5.2, 1.5.4, 1.5.8, 1.5.10, 1.5.11, 1.6.1, 1.6.3, 1.7.3, 1.7.4.1, 1.7.4.2.

Fabrikanten erklærer, at der er udarbejdet speciel teknisk dokumentation til denne delmaskine iht. 2006/42/EF Maskindirektivet, bilag VII, del B.

Fabrikanten forpligter sig til at overdrage den specielle tekniske dokumentation til myndigheden for markedskontrol efter en begrundet anmodning.

Fuldmægtig for oprettelse af den tekniske dokumentation:

Navn:	4TECH Robotics ApS
Adresse:	Bülowsgade 36
Postnr. og by:	DK-8000 Aarhus C

Ibrugtagning af den denne delmaskine er ikke tilladt, så længe delmaskinen ikke er monteret i en maskine eller samlet til en maskine med andre dele, som er blevet erklæret som værende i overensstemmelse med bestemmelserne i 2006/42/EF Maskindirektivet herunder risikovurdering, brugsanvisning og EF-overensstemmelseserklæring iht. bilag II A.

Henning Forbech
Direktør og ejer
Aarhus, 5. februar 2020

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18 Applied Standards

Lavspændingsdirektivet – 2014/35/EU

EMC-direktivet – 2014/30/EU

Maskindirektivet – 2006/42/EF

DS/EN ISO 9409-1:2004
Industrirobotter – Mekaniske grænseflader – Del 1: Plader (Standarden er tilbagetrukket, men er fundet anvendelig til denne risikovurdering)
Manipulating industrial robots – Mechanical interfaces
Part 1: Plates

DS/EN ISO 10218-2:2012
Robotter og robotudstyr – Sikkerhedskrav til industrirobotter – Del 2: Robotsystemer og integration
EN ISO 10218-1:2011(E) [2006/42/EC]
Robots and robotic devices – Safety requirements for industrial robots
Part 2

DS/EN ISO 12100:2011
Maskinsikkerhed - Generelle principper for konstruktion - Risikovurdering og risikonedsættelse
Safety of machinery – General principles for design – Risk assessment and risk reduction

DS/EN ISO 13850:2015
Maskinsikkerhed - Nødstop - Principper for udformning
EN ISO 13850:2015 [Stop Category 1 - 2006/42/EC]
Safety of machinery – Emergency stop – Principles for design

DS/EN ISO 14118:2018
Maskinsikkerhed - Forebyggelse af uventet opstart
Safety of machinery – Prevention of unexpected start-up

DS/ISO/TS 15066:2016
Robotter og robotudstyr – Samarbejdende robotter

DS/ISO/TR 20218-1:2018
Robotter og robotudstyr – Sikker konstruktion af industrirobotsystemer – Del 1: Robotværktøjer
Robots and robotic devices – Safety requirements for industrial robots
Part 1: Robots

DS/EN 60204-1:2006 +A1:2009
Maskinsikkerhed - Elektrisk udstyr på maskiner - Del 1: Generelle krav
Safety of machinery – Electrical equipment of machines
Part 1: General requirements

4TECH Robotics Aps · Bülowsgade 36 · DK-8000 Aarhus C · +45 40 38 21 17 · CVR/VAT: DK-39328372 · www.toolchanger.eu

DS/EN 61000-6-1:2007
Elektromagnetisk kompatibilitet (EMC) - Del 6-1: Generiske standarder - Immunitet for bolig-, erhvervs- og letindustrimiljøer
Electromagnetic compatibility (EMC)

DS/EN 61000-6-3:2007
Elektromagnetisk kompatibilitet (EMC) - Del 6-3: Generiske standarder - Emissionsstandard for bolig-, erhvervs- og letindustrimiljøer

Arbejdstilsynets bekendtgørelse nr. 63.

At-vejledning D.6.1-5– Støj.

19 Glossary

19.1 Glossary

Alphabetic index of expressions, terms and names used in this document:

Back Door
: A position under a docking station. The tool pick-up sequence starts from this point and the tool drop-off sequence ends at this point. See chapter 5.2 and “Front Door”.

Dock Center Point
: A position in the center of a docking station. This point is also known as the docking station center point. See chapter 5.2.

Docking Station
: The parking place for tools that are not mounted on the robot arm. The docking station for the Kelvin Tool Changer is designed with a docking plate (dock plate) that is mounted with rubber mounts on a base plate. This flexible docking plate is covered by the patent for the Kelvin Tool Changer.

Dock Plate
: The steel plate with the cut out for the tool plate.
This plate is engraved with the Kelvin logo, patent information and an arrow showing the position of the index notch.

Dock-M
: The position where the user can manually change tools on the robot arm. This is a fixed position (or pose) where the robot arm will stop and allow the operator to replace, mount or dismount a tool. Dock-M is treated as a docking station but it has no physical docking station. Tools can only be manually replaced when the robot is at a stop at Dock-M.

Dock-X
: A virtual docking station used by the Kelvin program during adjustments to a dockings station.

ToolFree
: A value that is normally set to “0”. Only when the tool changer is allowed to be opened manually or allowed to be open during tool changer operation is this value set to 1. If “ToolFree” is not set to 1 before the tool changer is unlocked the program will stop if the tool changer is not in the locked position.

Front Door
A position in front of a docking station. The tool drop-off sequence starts from this point and the tool pick-up sequence ends at this point. See chapters 5.2 and "Back Door".

Hook
The metal part in the master plate that connects to the metal bar in the tool plate. The hook holds the two parts together during operations. The hook has to be in the open position to mount a tool plate in the master plate.

Index Notch
A small cut out in the dock plate. When a tool plate is parked in the docking station a spring-loaded steel ball inside the tool plate will click into this notch and hold the tool plate in the right position for the next pick up.

Installation File
A file used by the robot program from Universal Robots. This file holds information on the safety of the robot. The installation file does not include the robot program but contains information on TCP. See chapters 9.4 and 9.5.

Installation Variables
A set of variables used in the UR program. These variables can be updated and are saved when the program is closed down. The installation variables hold information on the positions of the docking stations.

Kelvin Constraint
The connection between the two parts of the tool changer is based on a grid of steel balls that lock into each other. The tool plate has three steel balls and the master plate has a grid of three, two and one steel ball(s). When the two sets of steel balls lock into each other the two parts will be held in a locked position. All six degrees of freedom are locked with one connecting point locking each degree of freedom.
This type of constraint was first described by Lord Kelvin and is often described as a "Kelvin Constraint". The Kelvin Tool Changer has its name from this constraint and the use of this constraint for connecting end effectors to robot arms is the core of the patent for the Kelvin Tool Changer.

Locked Position
The locking ring is in the "Locked Position" when the tool plate is pulled up against the master plate and the ring is turned to the end stop where the ring is in a self-locking position.

Lock Open Position
When the hook is in the position where it is free of the metal bar in the tool plate the tool plate is free to move in and out of the

master plate. This position is called the lock open position. This position can be detected by the robot program.

Locking Ring
: The ring around the master plate. This ring is marked with an open and a closed lock pictogram to indicate which way to turn the ring to lock or unlock the tool changer. The locking ring is not holding the two parts together, it is only activating the locking mechanism.

Master Plate
: The fixed part of the tool changer that is mounted on the robot arm.

Tool Plate
: The free parts of the tool changer that can be mounted with different tools.

Tool Pick-up
: The process where the tool changer is connecting to a tool parked in the docking station.

Tool Drop-off
: The process where a tool is placed in a docking station and the tool changer disconnects from this tool.

Tool ID
: An electronic tag built into the tool plate that gives the tool plate a number value that can be detected by the robot controller. The tool ID is also marked with a small number tag in the center of the tool plate. See chapter 5.8.

TCP
: **T**ool **C**enter **P**oint. Movement of the robot arm is typically performed relative to this point. The robot controller will calculate the positions of joints in the robot arm to bring the TCP to a given position.

TCP_1
: Tool Center Point for the tool changer. This TCP is used for all docking operations with the Kelvin Tool Changer.

3M Surface Cleaner Sachet
: Paper napkin soaked with isopropyl alcohol, made by 3M.

4TECH Robotics ApS
: Manufacturer of the Kelvin Tool Changer.

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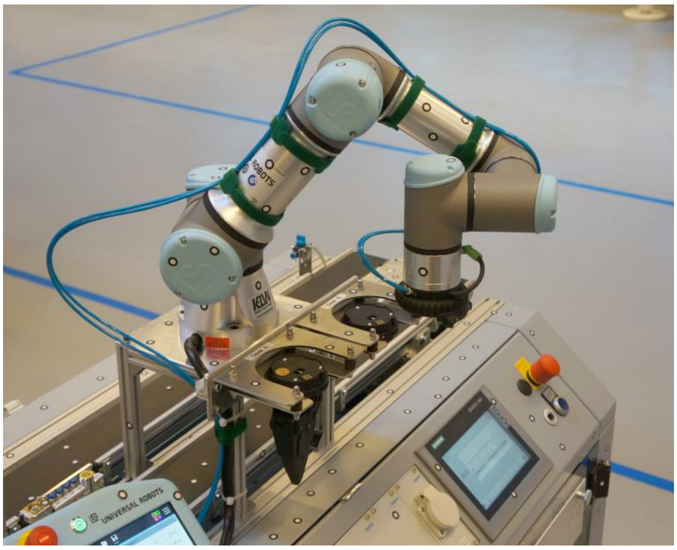
20 Quick Start

Kelvin Tool Changer



Quick Start

By Henning Forbech, 4TECH Robotics Aps
Version 1.1   15 April 2020

To use the Kelvin Tool Changer the robot must run the Kelvin program (Kelvin.urp). This Kelvin program is a kind of shell program that executes all the operations with the tool changer and allows the operator to run programs as subprograms.

At start up the Kelvin program will first move the robot arm to a fixed position. This is the "Ready" position and all programs start and end in this position. After a short check of the status for the robot the Kelvin program will ask the user which subprogram to run. Each subprogram has a number and when one job is finished the user can choose what to do next by entering the next task number.

The Kelvin program has some small standard programs to demonstrate the tool changer functions and some service programs for the robot installation.

The Kelvin program will handle all tool changer operations and will hand over the tool to the user program in the “Ready” position.

For first time users of the Kelvin Tool Changer it is recommended to run some of the simple demo programs just to see the basic function of the program and the hardware.

Feel free to test your own program on the robot. Take a look into the code for some of the standard programs to see the structure of the code.
A user manual can be found at the robot computer or downloaded from the url below.

Kelvin Programs:

1: Initializing Procedure
A self-test program that is automatically executed at the start of the Kelvin program. This program can also be used to check that the robot and the tool changer are ready for operation.

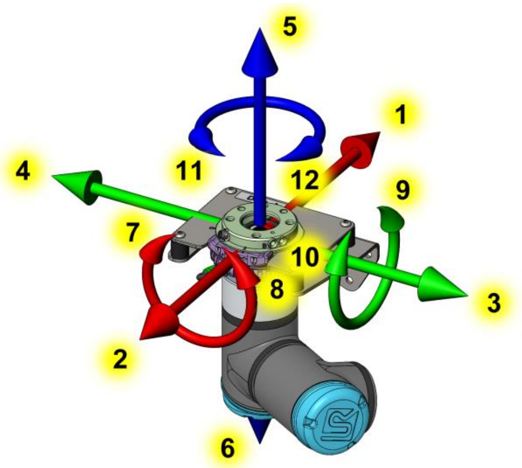
10: Demo: Tool-A
This program only picks up and drops off tool-A to demonstrate the basic tool changer functions.

13: Change between Tool-A, Tool-B and Tool-C
This program only picks up and drops off tool-A, B and C to demonstrate the basic tool changer functions.

14: Demonstrating manual Tool Change
Service program that allows the user to change the tool manually.

88: Full Menu
List of all programs set up for the Kelvin demonstration program.

0: End Program
This program will shut down the Kelvin program. The values that have been changed or updated are saved as Installations Variables and will be reloaded next time the program is started.



<- Numbers for fine tuning the position of docking station, see chapters 7.4 and #42

Comments and questions are welcome:
kelvin@toolchanger.eu

Download the full user manual here:

www.toolchanger.eu