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# SINTEF REPORT

TITLE

## State of the art on industrial robot systems for extreme environments

**KMB-project: Next Generation Robotics for Norwegian Industry**

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CLIENT(S)

Partners in the KMB-project

| REPORT NO. | CLASSIFICATION | CLIENTS REF. | |
|---|---|---|---|
| SINTEF A14051 | Unrestricted | NextGenRob Board of Administrators | |
| CLASS. THIS PAGE | ISBN | PROJECT NO. | NO. OF PAGES/APPENDICES |
| Unrestricted | 978-82-14-04462-1 | 90G376 | 16 |
| ELECTRONIC FILE CODE | | PROJECT MANAGER (NAME, SIGN.) | CHECKED BY (NAME, SIGN.) |
| Report NextGenRob Robots Extreme Environments.doc | | Ingrid Schjølberg | Mariann Merz |
| FILE CODE | DATE | APPROVED BY (NAME, POSITION, SIGN.) | |
| | 2010-01-05 | Sture Holmstrøm, Research manager | |

ABSTRACT

Robots are increasingly being introduced into new application areas and they can substitute high-cost manual labor in 4D (dirty, dull, distant or dangerous) environments. This can contribute to a reduction of production costs and improved environment, health and safety (EHS) issues, as well as growth in a global market. More and more industries see the benefit of replacing manual labor in extreme environments with robots. However, extreme environments can be tough on any equipment including robot manipulators. Many manufactures produce robots specialized for extreme environments and this report aims at giving an overview of these robotic systems for such environments. These environments include Ex-zones, high and low temperatures, and environments which require a high IP rating on equipment. Moreover, a short overview of some robot tools for use in such environments is also given.

This report is written in the KMB-project Next Generation Robotics for Norwegian Industry. The main objective of the KMB-project is to: *"Develop enabling robotics technology that meets Norwegian industry's need for robotic solutions for competitiveness and increased safety and efficiency for targeted applications."* One key aspect regarding this objective is robotic technologies for extreme environments.

| KEYWORDS | ENGLISH | NORWEGIAN |
|---|---|---|
| GROUP 1 | ICT | IKT |
| GROUP 2 | Robot | Robot |
| SELECTED BY AUTHOR | Extreme environments | Ekstreme miljø |
| | | |
| | | |

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# 1 Introduction

Robots are increasingly being introduced into new application areas, they have the potential of substituting high-cost manual labor in 4D (dirty, dull, distant or dangerous) environments. This can contribute to a reduction of production costs and improved environment, health and safety (EHS) issues, as well as growth in a global market. More and more industries see the befit of replacing manual labor in extreme environments with robots. However, extreme environments can be tough on any equipment including robots. Many manufactures produce robots specialized for extreme environments and this report aims at giving an overview of them.

This report is written in the KMB-project Next Generation Robotics for Norwegian Industry.
The main objective of the KMB-project is to

> *Develop enabling robotics technology that meets Norwegian industry's need for robotic solutions for competitiveness and increased safety and efficiency for targeted applications.*

The targeted applications have been identified and are detailed in memos developed in Work Package 4 (WP4) of the project. This report aims to survey robot manipulators available for use in extreme environments that are relevant to the identified targeted applications. More specifically, two cases have been found relevant for this report, the "Statoil case" and the "Hydro case" [6]. In the "Statoil case" robots will be placed in an outdoor offshore environment. As a result, the robots will be subject to a cold, moist and highly corrosive environment. In addition, all equipment used offshore must be Ex certified. In the "Hydro case" the robot will be used to clean anodes and the robot will be subjected to fine grained particles and dust.

In this report, the scope has been to do a market and literature study. The product range from three robot manufacturers has been studied (ABB, KUKA and Motoman). The main focus has been to study robot ratings and protection standards relevant to the environments described above.

In addition to the survey on robots for extreme environments, a selection of grippers and a swivel unit available for use in extreme conditions will be presented. This selection of tools serves as an overview regarding which considerations must be made on the choice of robot tools for extreme environment.

## 2 Explosive environments

Potentially explosive environment are divided into zones where the classification given to a particular zone depends on the likelihood of an explosive atmosphere to occur. For areas with a potential for explosive gas vapor the areas are divided into zone 0, 1 or 2

| | |
|---|---|
| 0 | *A place in which an explosive atmosphere is present all of the time (over 1000 hours/year or >10% of the time)* |
| 1 | *A place in which an explosive atmosphere is likely to occur in normal operation occasionally (0.1–10% of the time)* |
| 2 | *A place in which an explosive atmosphere is not likely to occur in normal operation but if it does, it only occurs for short periods of time (0–0.1% of the time)* |

A similar classification also exists for explosive dust.

All equipment for use in potentially explosive environments must be classified for use in that respective zone or lower. ATEX directive equipment certified for use in potentially explosive areas are marked with the 'Ex' symbol and a code to show the type and level of protection applied. An example could be as follows: **Ex II 3G EEx p IIB T4** where

- II means non-mining - the first letters after the Ex mark shows the "Equipment Group"
- 3 indicates the "Equipment Category". Zone 0 requires category 1 marked equipment, zone 1 requires category 2 marked equipment or lower and zone 2 requires category 3 marked equipment or lower,
- G in this example means gas - the letter tells the type of explosive atmosphere the equipment is classified for,
- EEx p tells us what kind of protection is used. In this example the equipment is pressurized or purged,
- IIB is the "Gas Group" the equipment is designed to be protected against, and
- T4 is the temperature classification which tells the maximum surface temperature that any part of the equipment can reach during normal operation or failure conditions, assuming an ambient temperature of 40 °C. T4 means maximum surface temperature can be 135 °C.

For more information about Ex and labeling see Table 1 and [1].

**Table 1: ATEX guideline Equipment Group II[1].**

| **Equipment Group II (explosive atmospheres of gas/air or dust/air mixtures, mist or vapors** | | | |
|---|---|---|---|
| **Equipment Category 2** | | **Equipment Category 3** | |
| **G** | **D** | **G** | **D** |
| Gas<br>Zone 1 | Dust<br>Zone 21 | Gas<br>Zone 2 | Dust<br>Zone 22 |
| For devices providing a high level of safety.<br><br>Designed for situations where a potentially explosive atmosphere is present | | For devices providing a moral level of safety.<br><br>Designed for situations where potentially explosive atmospheres are seldom or only briefly present. | |

[1] "Explosion protection in Schunk Premium Modules", accessed 15 Dec 2009
http://www.schunk.com/schunk_files/attachments/SCHUNK_ATEX_Flyer_EN.pdf

Special design methods are described for electrical equipment for use in areas with vapors, gases and mists. These are assigned to "ignition protection categories" and more than one category can be combined in one unit. An overview of the ignition protection categories are found in Table 2.

**Table 2: Ignition protection categories**

| Ignition protection categories | Identification | Zone | Safety principle |
|---|---|---|---|
| Increased safety | EEx e | 1 | No arch, sparks or hot surfaces |
| Non-sparking equipment | EEx nA | 2 | |
| Pressurized encapsulation | EEx d | 1 | Controls an internal explosion and extinguishes the flame |
| Sand encapsulation | EEx q | 1 | |
| Enclosed switching device | EEx nC | 2 | |
| Intrinsic safety (special requirements) | EEx ia | 0 | Limits the energy of the sparks and the temperature of the surface |
| Intrinsic safety | EEx ib | 1 | |
| Energy-limiting equipment | EEx nL | 2 | |
| Encapsulation | EEx m | 1 | Separates source of ignition from potentially explosive atmosphere |
| Oil encapsulation | EEx o | 1 | |
| Pressurization | EEx p | 1 | |
| Simplified pressurization | EEx nP | 2 | |
| Vapor-proof housing | EEx nR | 2 | |

In this report the equipment categories and allowable zones are emphasized, but all information about Ex-classification from the robots data sheets are quoted for complete reference.

Available robots with Ex-certification from the studied robot suppliers are presented in the following. The robot controllers have not been studied because it is assumed that it can be placed either outside the potentially explosive zone or placed inside a protective container.

### 2.1 ABB, Ex-certification

ABB has a range of painting robots, all of which are Ex certified for use in areas at risk of gas explosions, zone 1 (group IIB, category 2 and temperature class T4). These robots are pressurized or purged to create a positive pressure inside the robot, prohibiting explosive gasses from penetrating into cavities.

The robots are all rated IP 67 while their wrists are rated to IP 54. (See chapter 3 for more information on IP ratings)

See Table 2 for a complete reference of all available ABB painting robots with Ex certification.

**Table 3: Ex-certified ABB robots**[2]

| | **Loads** | **Working envelope** | **Ex –classification** (from data sheet) | **Other data** |
|---|---|---|---|---|
| **IRB52**  | Payload: 7 kg | Reach: 1,2 – 1,45 m | Explosion protected Exi/Exp for installation in hazardous area, Zone 1 (Europe) and Division I, Class I & II | Repeatability: 0,15mm<br>Weight: 250 kg<br>Mounting positions: Floor, inverted, wall, tilted<br>**IP rating**: Robot IP 67, Wrist IP 54 |
| **IRB 5400**  | Payload: 25 kg | Reach: 3,10 – 3,50 m | North America Class I, II. Division 1, Group C, D, G. 135°C<br>Japan II G T4<br>Europe II 2 G D (T65°C) | Repeatability 0,15mm<br>Weight 790 kg<br>Mounting positions: Floor, wall, tilted<br>**IP rating**: Robot IP 67, Wrist IP 54 |
| **IRB 540**  | Payload: 5 kg | Reach: 1,70 – 2,60 m | II 2 G Ex ib px IIB T4<br>II 2 D Ex pD 21<br>T65°C<br>FM Class I,II. Div.1, Group C,D,G 135°C | Repeatability 0,15mm<br>Weight 610 kg<br>Mounting positions: Floor, inverted<br>**IP rating**: Robot IP 67, Wrist IP 54 |
| **IRB 5500**  | Payload: 13 kg | Reach: 5,3 m | II 2 G Ex ib px IIB T4<br>II 2 D Ex pD 21<br>T65°C<br>FM Class I,II. Div.1, Group C,D,G 135 °C | Repeatability 0,15 mm<br>Weight 540 kg<br>Mounting positions: Floor, wall, tilted, inverted<br>**IP rating**: Robot IP 67, Wrist IP 54 |
| **IRB 580**  | Payload: 10 kg | Reach: 2,2 - 2,6 m | II 2 G Ex ib px IIB T4<br>II 2 D Ex pD 21<br>T65°C<br>FM Class I,II. Div.1, Group C,D,G 135°C | Repeatability 0,3 mm<br>Weight 630 kg<br>Mounting positions: Floor, rail, inverted<br>**IP rating**: Robot IP 67, Wrist IP 54 |

[2] More information on Ex-certified ABB robots can be obtained from:
http://www.abb.com/product/ap/seitp327/885acba02219182bc1257066003f863a.aspx

## 2.2 KUKA, Ex-certification

KUKA offers two robots for use in potentially explosive environments zone 2 (group IIB, category 3 and temperature class T3). The robots are rated IP 64. Optional wrist that is rated to IP 67 is available.

See Table 4 for a complete reference of all available KUKA Ex certified robots.

**Table 4: Ex-certified KUKA robots**[3]

| | **Loads** | **Working envelop** | **Ex – classification** | **Other data** |
|---|---|---|---|---|
| **KR 30 L16-2 EX**   | Payload: 16kg Supplementary load: 45kg | Max. Reach: 3102mm | II 3G EEx c,nA IIB T3 X | Repeatability: <+- 0,15mm<br>Weight: 700 kg<br>Mounting positions: Floor, ceiling<br>**IP rating**: IP 64<br>Wrist: IP 67 with Foundry option |
| **KR 16-2 EX**   | Payload: 16kg Supplementary load: 10kg | Max. Reach: 1610mm | II 3G EEx c,nA IIB T3 X | Repeatability: <+- 0,1mm<br>Weight: 235 kg<br>Mounting positions: Floor, ceiling, wall<br>**IP rating**: IP 65<br>Wrist: IP 67 with Foundry option |

[3] More information about Ex-certified KUKA robots can be obtained from:
http://www.kuka-robotics.com/en/products/industrial_robots/special/atex_compliant_robots/start.htm

### 2.3 Motoman, Ex-certification

Motoman has a range of painting robots that are all Ex certified for use in areas at risk of gas explosions, zone 1 (group II, category 2 and temperature class T4). These robots are pressurized or purged.

**Table 5: Ex-certified Motoman robots**[4]

| | Loads | Working envelope | Ex –classification (from data sheet) | Other data |
|---|---|---|---|---|
| EPX2800R  | Payload: 15 kg | Reach: 2825 mm | Ex px II T4<br>Ex pD 21 Tmax 135 °C | Repeatability: 0,5mm<br>Weight: 820 kg<br>Mounting positions: Wall |
| EPX2900  | Payload: 20 kg | Reach: 2900 mm | II 2 G EEx p II T4 c II T4 | Repeatability 0,5mm<br>Weight 1030 kg<br>Mounting positions: Floor |
| PX1750  | Payload: 15 kg | Reach: 1757 mm | Ex II 2 G<br>EEx p II T4 c II T4 | Repeatability 0,5mm<br>Weight 410 kg<br>Mounting positions: Floor, wall, roof |
| PX2050  | Payload: 10 kg | Reach: 2035 mm | II 2 G<br>EEx p II T4 c II T4 | Repeatability 0,5 mm<br>Weight 370 kg<br>Mounting positions: Floor, wall, roof |

### 2.4 Summarization – Robots for use in potentialy exposive environments

Both ABB and Motoman have a large range of robots classified for use in Ex zone 1. These are painting robots and thus might have limited payload compared to other robots. Kuka have one robot clasified for zone 2 with a somewhat higher payload. None of the studied robot suppliers had robots certified for zone 0 in their standard product range

[4] More information about Ex-certified Motoman robots can be obtained from: http://www.motoman.eu/se/Losningar/Applikationsomraden/Malning-/

# 3 IP Rating

The content of this section is quoted from Wikipedia: http://en.wikipedia.org/wiki/Ip_rating.

*The IP Code (or International Protection Rating, sometimes also interpreted as Ingress Protection Rating) consists of the letters IP followed by two digits and an optional letter. As defined in international standard IEC 60529, it classifies the degrees of protection provided against the intrusion of solid objects (including body parts like hands and fingers), dust, accidental contact, and water*

**First digit**

*The first digit indicates the level of protection that the enclosure provides against access to hazardous parts (e.g., electrical conductors, moving parts) and the ingress of solid foreign objects*

| Level | Object size protected against | Effective against |
|---|---|---|
| **0** | — | No protection against contact and ingress of objects |
| **1** | >50 mm | Any large surface of the body, such as the back of a hand, but no protection against deliberate contact with a body part |
| **2** | >12.5 mm | Fingers or similar objects |
| **3** | >2.5 mm | Tools, thick wires, etc. |
| **4** | >1 mm | Most wires, screws, etc. |
| **5** | dust protected | Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment; complete protection against contact |
| **6** | dust tight | No ingress of dust; complete protection against contact |

**Second digit**

*Protection of the equipment inside the enclosure against harmful ingress of water*

| Level | Protected against | Details |
|---|---|---|
| **0** | not protected | — |
| **1** | dripping water | Dripping water (vertically falling drops) shall have no harmful effect. |
| **2** | dripping water when tilted up to 15° | Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle up to 15° from its normal position. |
| **3** | spraying water | Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect. |
| **4** | splashing water | Water splashing against the enclosure from any direction shall have no harmful effect. |
| **5** | water jets | Water projected by a nozzle against enclosure from any direction shall have no harmful effects. |
| **6** | powerful water jets | Water projected in powerful jets against the enclosure from any direction shall have no harmful effects. |

| | | |
|---|---|---|
| **7** | immersion up to 1 m | Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion). |
| **8** | immersion beyond 1 m | The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. NOTE: Normally, this will mean that the equipment is hermetically sealed. However, with certain types of equipment, it can mean that water can enter but only in such a manner that produces no harmful effects. |

A summary of the robots with the highest IP rating from the different robot suppliers is given in the following. The highest IP rating on robots from ABB, KUKA and Motoman are found on so called *foundry* robots. A foundry robot is a robot made to withstand foundry environments which means

- High temperatures
- Dusty and dirty environments
- Corrosive gases or fluids

### 3.1 ABB, IP Rating

The ABB robots with the *Foundry Plus* option [7] have an additional sealing to prevent steam and particles from penetrating into cavities, a corrosion-proof coating of special anti-rust primer under a layer of two-component epoxy paint and special protection of cabling and electronics. The entire robot is **IP 67** compliant from base to wrist, highly resistant to corrosion and has capability to withstand high-pressure steam washing.

Foundry plus option is available for the following ABB robots:

| | | | | | |
|---|---|---|---|---|---|
| IRB 140 | IRB 1600 | IRB 2400 | IRB 4400 | IRB 4450S | IRB 7600 |
| IRB 6400RF | IRB 6620 | IRB 6640 | IRB 6650S | IRB 6660 | |

ABB robots with the *Foundry Prime* option [8] have a 3 layer epoxy paint especially for extreme environments. The robot itself consists of anticorrosive parts and works with pressurized motors purpose-built against permeation of humidity. Robots protected with Foundry Prime withstand 100 % humidity and water vapor of a typical water jet cleaning applications and ensure a long-life cycle in the aggressive environment of a cleaning cell. In the very specific application of water jet cleaning with high humidity the robot can operate at moderate speed with a cleaning bath temperature up to 60 degrees Celsius. Foundry prime robots have IP rating 67.

Foundry prime option is available for the following ABB robots:

| | | | |
|---|---|---|---|
| IRB 4400/60 | IRB 6640 | IRB 6650S | IRB 7600 |

### 3.2 KUKA, IP Rating

KUKA foundry robots [9], [10] are fitted with an in-line wrist that withstands temperatures of up to 100 °C in continuous operation and peaks of 180 °C for up to 10 seconds every minute. It uses pressurized regulators and overpressure in the arm housing to protect against penetration of aggressive fluids or gases from the outside. Additional seals are used at the interface of the arm extension, the arm housing, the counter-balance system, axis motors and the wrist.

The robots are painted with a triple coat two component paint for better impact-resistance, hard wearing and resistance against acids or alkalis. The robots are IP 65 compliant while the wrist is rated to IP 67

The following KUKA Foundry robots are available:

| | | | | |
|---|---|---|---|---|
| KR 16-2 F | KR 16-2 KS-F | KR 30-3 F | KR 30-3 KS-F | KR 60-3 F |
| KR 60-3 F | KR 60-3 KS-F | KR150-2 F | KR150-2 K-F | KR180-2 F |
| KR 180-2 K-F | KR 210-2 F | KR 210-2 K-F | KR 240-2 F | KR360-2 F |
| KR 360-2 F | KR500-2 F | KR 500 570-2 PA-F | KR 1000 L750 titan F | KR 1000 titan F |

### 3.3 Motoman, IP Rating

Motoman has a range of robots with bodies classified as **IP 65** and wrists classified as **IP 67** either as standard or optional. In addition, some models are also available as Foundry-hardened models which means that they are specifically suited for foundry environments [11].

The following Motoman robots are available with Foundry option:

| | | | | |
|---|---|---|---|---|
| EH80 | EH130 | SSF2000 | HP20 | HP20-6 |
| HP50-20 | HP50-35 | HP165 | DA9IC | |

## 4 Robot protection cover

The scope of this report has been to survey standard, "off-the-shelf" industrial robots from the mentioned manufacturers. It is also possible to get customized solutions to suite a robot for specific environments. For example, there exist several manufacturers that produce robot protection covers to shield the robot from a hostile environment. Figure 1 shows a pressurized robot protection cover from ASP specifically designed to protect the robot from dust or paint.

**Figure 1: Pressurized robot protection cover from ASP [12]**

Similar covers exists to protect against other hostile environments such as:

- Heat
- Cold
- Wet
- Abrasive
- Chemical
- Where special cleanliness is required.

Some covers include a ventilation system to maintain proper inflation, airflow, and to provide cooling and humidity control under dynamic conditions. Heated air can be used if the robot is situated in an extreme cold environment.

## 5 Extreme temperatures

Foundry robots are designed to work in very high temperatures. However, none of the studied robot suppliers have robots for very low temperatures. According to the datasheets of the studied robots the lowest approved ambient temperatures are around 0-5 °C. Still robots are successfully being used outside at temperatures below -20°C in Norway today. According to the robot

suppliers this is possible as long as certain precautious are being made. These include making sure of continuous movement of the robot at all times or including a protection cover as described in chapter 4. Such precaution measures have to be worked out in close collaboration with the robots suppliers.

# 6 Robots used in extreme environments in Norway

To our knowledge a complete overview of robots used in extreme environments does not exist. However, Figure 2 shows an overview of all robots installed and in operation in Norwegian industry from 2003-2008 sorted by application area. In general, operations such as handling operations for metal casting, painting and enameling, and water jet cutting require robots that are able to operate in harsh environments. Robots are installed and operate in all these areas in Norway according to Figure 2.

Operational stock of industrial robots at the end of the year. Unit distribution by application areas

| IFR class | Application area | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2008/ 2007 |
|---|---|---|---|---|---|---|---|---|
| **000** | **Unspecified** | 30 | 43 | 40 | 70 | 73 | 78 | 7% |
| **100** | **Handling operations/ Machine tending** | **341** | **351** | **434** | **531** | **579** | **604** | **4%** |
| 111 | Handling operations for metal casting | 25 | 22 | 34 | 52 | 52 | 51 | -2% |
| 112 | Handling operations for plastic moulding | 6 | 6 | 19 | 40 | 52 | 68 | 31% |
| 113 | Handling operations for stamping/forging/ bending | 21 | 19 | 33 | 39 | 36 | 30 | -17% |
| 114 | Handling operations at machine tools | 112 | 111 | 129 | 139 | 159 | 154 | -3% |
| 115 | Machine tending for other processes | 6 | 9 | 10 | 15 | 27 | 28 | 4% |
| 116 | Handling operations for measurement, inspection, testing | 6 | 6 | 6 | 7 | 6 | 6 | |
| 117 | Handling operations for palletizing | 87 | 100 | 128 | 159 | 157 | 163 | 4% |
| 118 | Handling operations for packaging, picking and placing a/ | | | | | | | |
| 119 | Material Handling n.e.c. | 78 | 78 | 75 | 80 | 90 | 104 | 16% |
| | Handling operations/ Machine tending unspecified | | | | | | | |
| **160** | **Welding and soldering (all materials)** | **139** | **143** | **153** | **158** | **161** | **151** | **-6%** |
| 161 | Arc welding | 139 | 142 | 152 | 157 | 158 | 148 | -6% |
| 162 | Spot welding | | | | | | | |
| 163 | Laser welding | | | | | 2 | 2 | |
| 164 | other welding | | 1 | 1 | 1 | 1 | 1 | |
| 165 | Soldering | | | | | | | |
| | Welding and soldering unspecified | | | | | | | |
| **170** | **Dispensing** | **34** | **36** | **34** | **33** | **30** | **26** | **-13%** |
| 171 | Painting and enamelling | 23 | 25 | 22 | 22 | 19 | 15 | -21% |
| 172 | Application of adhesive, sealing material or similar material | 6 | 6 | 6 | 6 | 6 | 6 | |
| 179 | Dispensing others/ Spraying others | 5 | 5 | 6 | 5 | 5 | 5 | |
| | Dispensing unspecified | | | | | | | |
| **190** | **Processing** | **91** | **96** | **92** | **101** | **101** | **97** | **-4%** |
| 191 | Laser cutting | | | | | | | |
| 192 | Water jet cutting | 7 | 7 | 8 | 8 | 7 | 7 | |
| 193 | Mechanical cutting/grinding/ deburring/ milling/polishing | 76 | 81 | 76 | 83 | 84 | 80 | -5% |
| 199 | Other processing | 8 | 8 | 8 | 10 | 10 | 10 | |
| | Processing unspecified | | | | | | | |
| **200** | **Assembling and disassembling** | **31** | **38** | **40** | **44** | **46** | **44** | **-4%** |
| 201 | Fixing, press-fitting | 25 | 25 | 25 | 24 | 24 | 24 | |
| 202 | Assembling/ mounting/ inserting | 6 | 13 | 15 | 20 | 22 | 20 | -9% |
| 203 | Disassembling | | | | | | | |
| 209 | Other assembling | | | | | | | |
| | Assembling and disassembling unspecified | | | | | | | |
| **900** | **Others** | **17** | **17** | **18** | **23** | **22** | **31** | **41%** |
| 901 | Cleanroom for FPD | | | | | | | |
| 902 | Cleanroom for semiconductors | | | | | | | |
| 903 | Cleanroom for others | | | | | | | |
| 999 | Others | 17 | 17 | 18 | 23 | 22 | 31 | 41% |
| | **TOTAL** | **683** | **724** | **811** | **960** | **1.012** | **1.031** | **2%** |

Sources: IFR, TBL and UNECE (up to 2004).
a/ included in handling operations for palletizing.

**Figure 2**: Operational stock of industrial robots in Norway at the end of the year, **World Robotics 2009, IFE - International Federation of Robotics**

To get an overview of the extent of use of robots in extreme environments in Norway, a questionnaire was made and sent to leading Norwegian robot suppliers. The following questions were asked: Have your company, during the last 3 years, …

- … delivered robots for use in a potentially explosive environment?
- … delivered robots for use in environments with strong magnetic disturbances?
- … delivered robots for use in an outdoor environment?
- … delivered robots for use in a marine environment?
- … delivered robots for use in a corrosive environment?
- … delivered robots for use in other environment also considered as extreme?
- … delivered robotic solutions subject to strong vibrations (e.g. chiselling)?

The details regarding the answers to the questionnaires are confidential so these can not be revealed in this report. However, it can be concluded that Norwegian robot suppliers have delivered robots which have been or are in use in all of the above mentioned extreme environments.

# 7 Robot tools for extreme environments

There are a vast number of tools available for robot manipulators. Some of the main categories of robot tools are: gripping modules, rotary and swivel modules, and linear modules. In addition, a large range of various off-the-shelf or custom built tools are also available. These are, for example, tools for milling, polishing, welding, grinding, and deburring. Although the selection of available robot tools is vast, this selection is greatly reduced for robot tools when specifications such as ATEX certification and/or capability to operate in extreme temperatures are added.

The purpose of this section is to give a short overview of some robot tools that are available for use in Ex and/or high-temperature environments. The product range of Schunk GmbH & Co, a leading supplier of robot tools and accessories, is used as a basis for the material presented in the following. The product range of other suppliers should also be investigated before final decisions on tool selections are made. However, the product range of Schunk gives a good indication on what possibilities there are with regards to making such a decision. A brief overview of other possible robot tools by other suppliers is given at the end of this section.

## 7.1 Tool actuation principles and design materials

The three most common types of actuation for robot tools are electric, pneumatic, and electro-pneumatic. Hydraulic systems are also available. Tools with ATEX certification are usually pneumatic.

In addition to the principle of actuation, it is also important which materials a tool is composed of and/or its coating for compliance with ATEX directives. Manually operated tools (hammers, wrenches, etc) composed of Aluminum-Bronze (AlBr) or Copper-Beryllium (CuBe2) are available for use in Ex zones 0, 1 and 2 [5]. It is not found that any of the robot tools included below are composed of such materials. However, the design of the manual tools may serve as an inspiration for the choice of materials in robot tools.

### 7.2 Gripping modules

Among robot tools, it is found that mostly gripping modules, or "grippers", are available with ATEX certification and/or the possibility for use in areas with extreme temperatures. In this section, a selection of such grippers is presented.

Gripping modules range from simple 2-finger parallel grippers with limited sensor feedback to advanced articulated robot "hands" with multi-point tactile feedback. It is not found that the latter category has yet been employed for industrial purposes. Therefore, the focus will be on simpler grippers in the following.

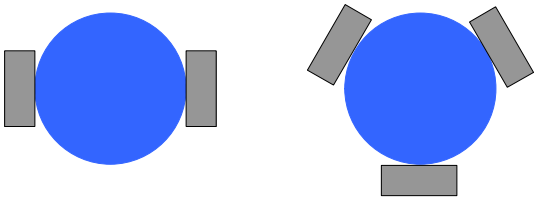

**Figure 3. Illustration of arrangement of fingers on a 2-finger parallel gripper (left) and a 3-finger centric gripper (right) grabbing a blue circular object.**

The most common type of gripper is a 2-finger parallel gripper. Parallel grippers differs from centric grippers in how the gripper fingers are arranged as illustrated in Figure 3. A considerably larger selection of types of pneumatic grippers is available compared to electric grippers.

Both 2-finger parallel grippers and 3-finger centric grippers are available as explosion protected modules. Table 6 gives an overview of various grippers with ATEX certification and high IP rating.

**Table 6: Pneumatic grippers from Schunk with ATEX certification with IP rating, gripping force and normal operating temperatures[5].**

| Equipment group II, Category 2 | | | |
|---|---|---|---|
| Gas | | Gas/dust | |
| PGN-plus 2-finger gripper  | PZN-plus 3-finger centric gripper  | DPG-plus sealed 2-finger parallel gripper  | DPZ-plus sealed 3-finger centric gripper  |
| IP-64 | IP-64 | IP-67 | IP-67 |
| 123 – 21800 N | 580 – 38000 N | 125 – 6230 N | 230 – 17150 N |
| -10 – 130 ˚C | -10 – 130 ˚C | -10 – 90 ˚C | -10 – 90 ˚C |

Off-the-shelf grippers can also be specially equipped for particularly harsh environments. One such example is the use of a Schunk PFH 30 2-finger pneumatic gripper for removal of red-hot forged parts where the gripping module was subjected to temperatures up to 1100 ˚C [4].

### 7.3 Swivel unit

In addition to grippers, a swivel unit is also available from Schunk with ATEX certification. A swivel module is much the same as a rotary module. The difference is that a swivel unit can usually only be in one of two or three different positions (e.g., 0 and 90 degrees) while a corresponding rotary module can be positioned in "any" of the positions from 0 to 90 degrees.

[5] More data on all Schunk grippers can be obtained from: http://www.schunk.com/schunk/schunk_websites/products/products.html?product_level_1=244&product_level_2=250&product_level_3=0&&country=INT&lngCode=EN&lngCode2=EN

A swivel unit (Schunk SRU-plus universal swivel) is available for use in Equipment Group II, Category 2, Zone 1 (gas).

### 7.4 Other robot tools

Other more specialized tools are also available for robots. In this section, a brief presentation of selected tools are presented. Specifications regarding ATEX certification and IP category have not been found for these tools.

Robot deburring and surface-finishing tools are available from, e.g., ATI Industrial Automation[6] (see figure to the left) [13]. Since deburring processes may generate a large amount of fine particles it is natural to assume that the available tools can operate in such environments. Robotic milling can also be carried out, and one example is given where an ABB IRB6400 robot is fitted with an ELTE TMA4 Spindle for milling[7].

Brokk AB[8] is a company that delivers mobile remote controlled robots for, e.g., demolition of concrete structures. The smallest robot, called Brokk 50, can be fitted with a Brokk SB52 chiselling hammer (illustration to the right). The tool weighs about 60 kg so it would require a very large industrial robot manipulator.

## 8 Conclusion

The overview presented in this report shows that robot manipulators are available and being used for various applications in extreme environments in Norway. Robot manipulators are available with IP rating 67 and for use in areas with risk of gas explosions (Ex: zone 1, group IIB, category 2 and temperature class T4). It is also found that custom modifications can be performed on robot systems to increase the range of temperatures in which they can operate. Hence, a close interaction with a robot supplier is necessary in order to modify, install and maintain a robot manipulator in an extreme environment.

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