# Content




**Shu YunHua | White paper validation**

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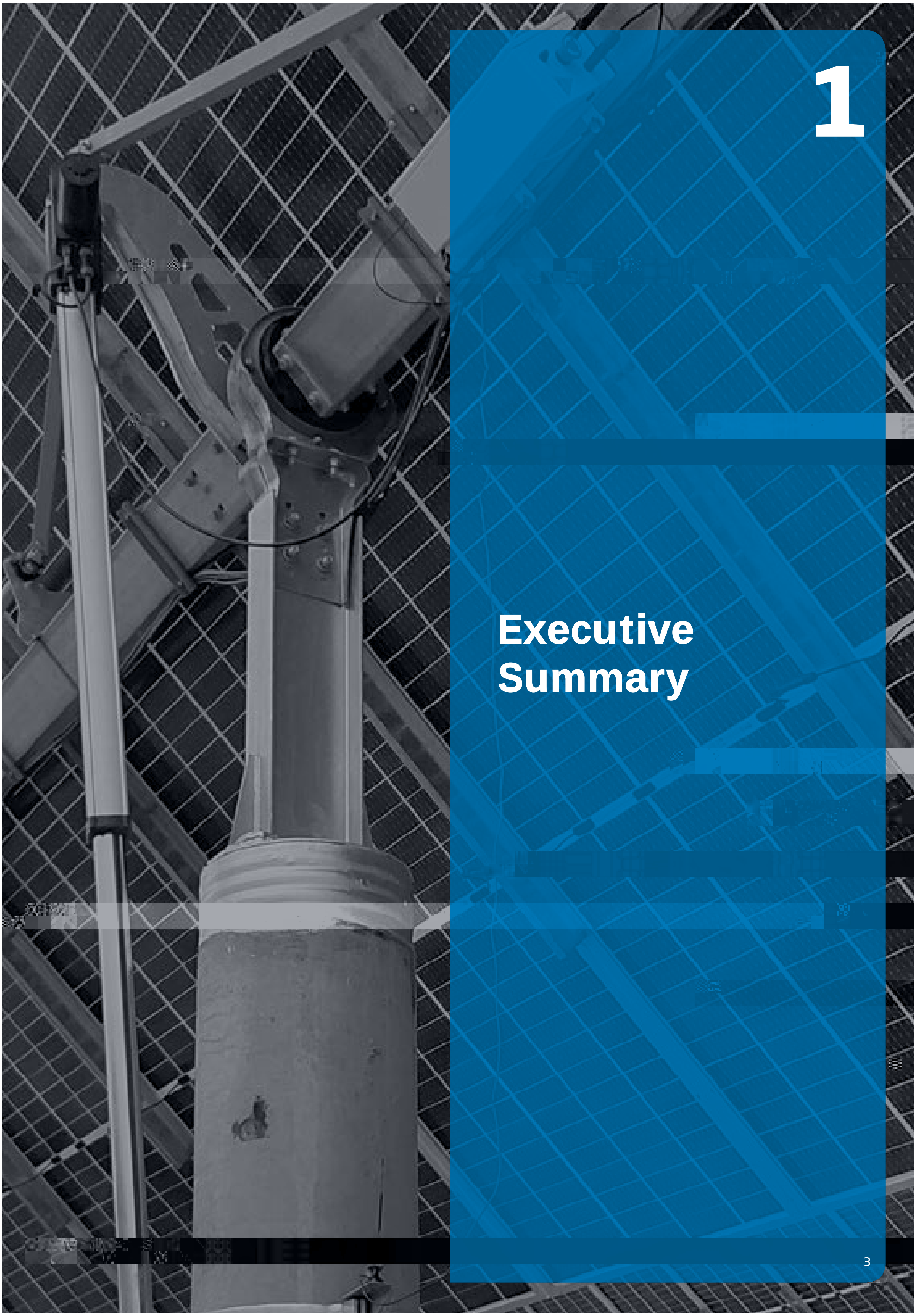

# 1

# Executive Summary

# 1 Executive Summary

**Alignment**

The correct position of the components of the tracker to be able to track the sun correctly

**Bends**

Deformations and deflections caused in the poles during their installation

**BOS cost**

Cost of Balance of System will include the cost of the hardware (and software, if applicable), labour, permitting Interconnection and Inspection (PII) fees, and any other fees that may apply. For large commercial solar systems, the cost of BOS may include the cost of land and building, etc. The cost of BOS can be about two thirds of the total cost.

**CPP**

Cermak Peterka Petersen, Inc.

**DNV**

Det Norske Veritas

**EPC**

Engineering, Procurement and Construction

**FEM**

Finite Element Method

**Galvanized**

A process that protects against corrosion

**Internal ribs**

Reinforcements on the inside of the plastic parts

**LCOE**

Levelized Cost of Energy (LCOE), or Levelized Cost of Electricity, is a measure of the average net present cost of electricity generation for a generating plant over its lifetime

**Magnelis**

An exceptional metallic coating that provides a breakthrough in corrosion protection

**MTBF**

Mean Time Before Failures

**O&M**

Operation and Maintenance

**Piles**

Post rammed into the ground

**Plastic injection**

A method for obtaining plastic parts by injecting plastic into a mould

**PV**

Photovoltaic

**Radial loads**

The loads on the bearing from the centre of the bearing in the direction of the radius

**R&D**

Research and Development

**ROI**

Return on Investment (ROI) is a performance measure used to evaluate the efficiency or profitability of an investment or compare the efficiency of several different investments

**RWDI**

Rowan Williams Davies & Irwin Inc.

**Torque tube**

The profile that rotates along with the **Spherical Bearings** allowing tracking of the sun

**Bloomberg New Energy Finance** (BNEF) estimated that between now and 2050, 77% of investments in new power generation will be in renewables.

Specifically, utility-scale photovoltaic energy has become an attractive investment area since installation and interconnection times are short, and it involves low risk, since energy production can be easily predicted.

The reliability of solar power plants depends on how accurately the solar trackers can follow the course of the sun. The more precisely these solar systems operate, the more efficient and the more profitable the plants will, therefore, be.

The quality of solar trackers is the key to making PV projects reliable assets. Moreover, the **bankability** of projects is mostly evaluated by the quality of system components.

Therefore, bearings make an important contribution here since they are critical for the reliability and cost effectiveness of the solar power plant. These components must have high rigidity and high load-carrying capacities even when operating under extreme conditions.

**TrinaTracker**'s **Research and Development Department** (R&D) is continuously developing improvements in the quality and design of all components in the trackers, thus increasing their reliability, and decreasing failure rates.

The company strives to be at the forefront of innovation and technology and its patented **spherical bearing**, which is unique in the photovoltaic market, is a result of its endeavour to maintain its positioning as a **technological pioneer** in the solar industry.

**TrinaTracker** offers long-lasting reliable products that achieve optimized production, and increase the life expectancy of the installation while reducing **BOS** and **LCOE** to provide maximum **ROI** to their customers.

# 2

# Introduction

# 2 Introduction

**TrinaTracker works non-stop to better its design and o□er trackers that include the most innovative components. Many of the components are unique in the market, like the patented "Spherical Bearing"**

Regarding solar trackers, the design optimization of any component can contribute to achieving a more accurate rotation movement to follow the sun and capture most of the existing radiation in a particular site.

When it comes to innovation and technology, **TrinaTracker**, is always.

The company works non-stop to better its design and offer trackers that include the most innovative components. Many of the components are **unique in the market**, like the patented "**Spherical Bearing**."

In general terms, a bearing is an element that allows the rotation of a torque tube on a fixed part or structure.

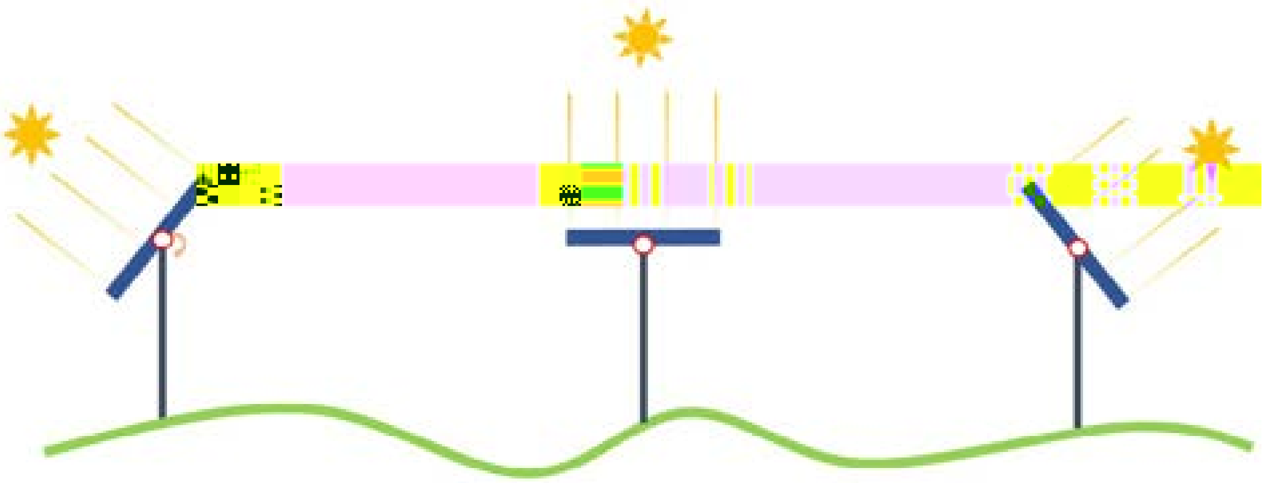

**Image 1:** Tracker rotation

The use of bearings in the photovoltaic sector arises from the need to make a semi-fixed structure that allows for tracking the sun's position to take advantage of solar energy throughout the sun's cycle.

The bearing assembly is one of the main parts of a tracker. Apart from being the component that allows the torque tube to rotate (and therefore the tracking of the sun), it is the element that **keeps the torque tube anchored to the piles**, and therefore it will have to withstand high vertical, horizontal, and axial loads.

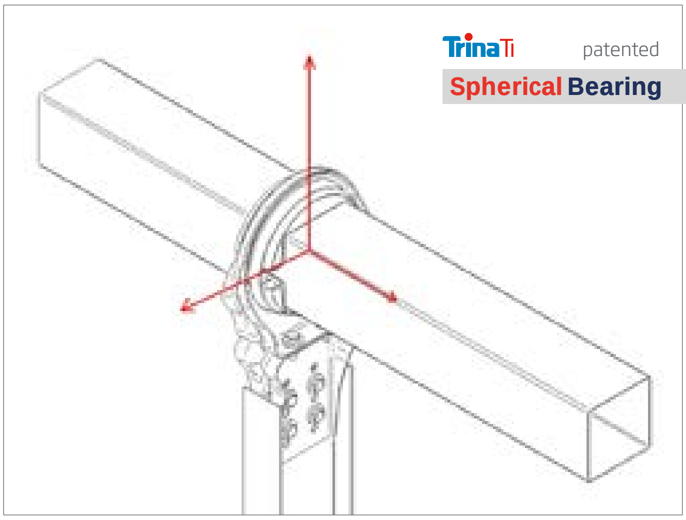


**Image 2:** Vertical, horizontal, and axial loads

**Image 3:** Tolerance on post twist

Without bearings, a single-axis tracker would only be a fixed structure. A good bearing design will allow for optimal tracking, minimizing energy losses due to friction. It will also allow **reduction of assembly time** and the **reduction and absorption of the twisting** generated from the driving in of the posts.

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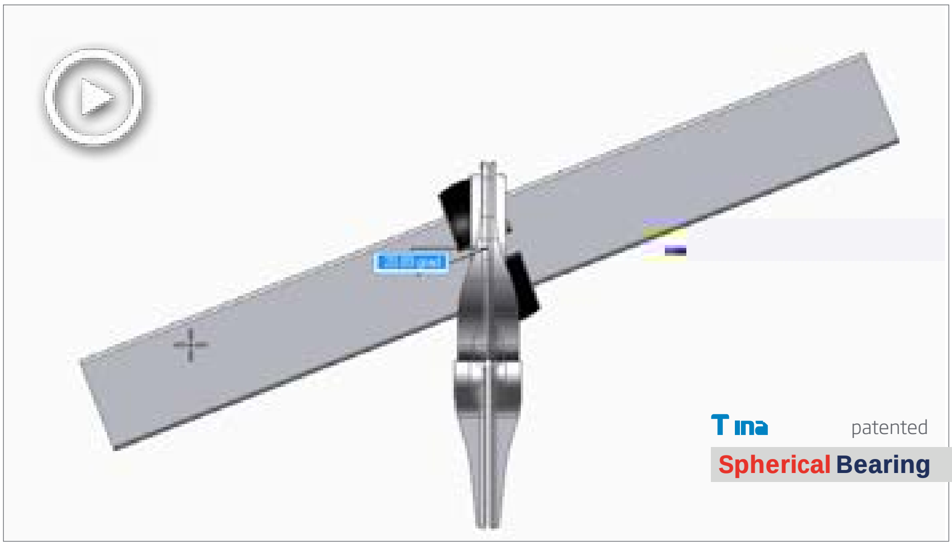
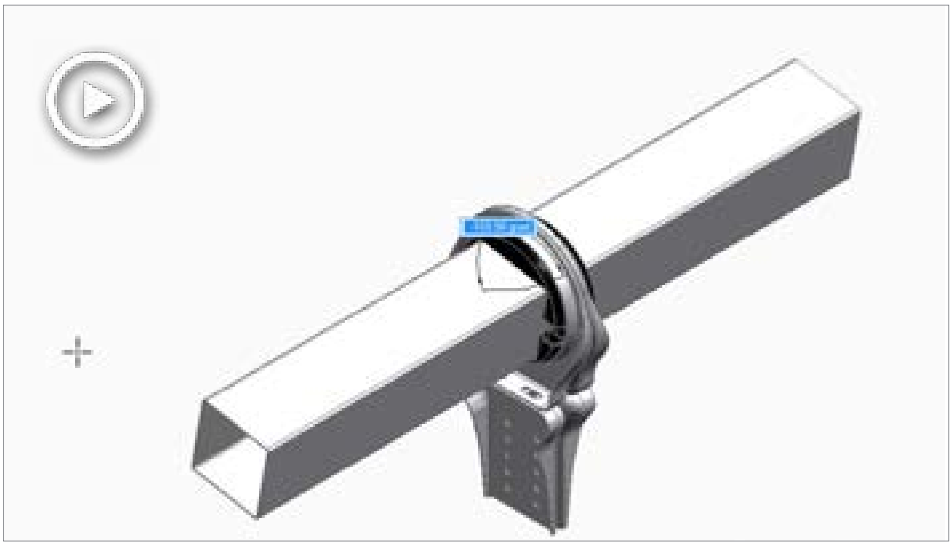
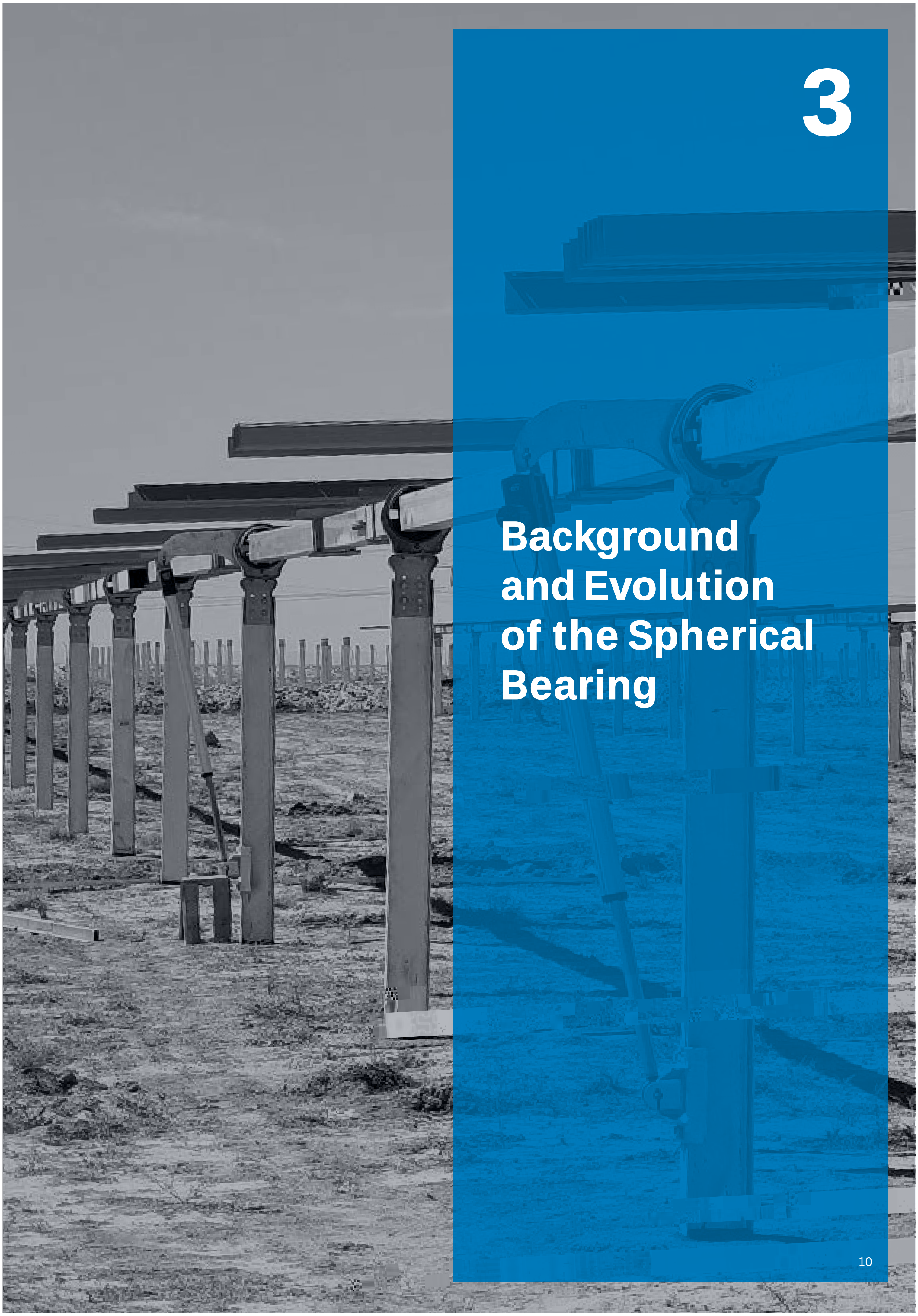



Video 1 : rotation



Video 2 : rotation



# 3

# Background and Evolution of the Spherical Bearing

3

# Background and Evolution of the Spherical Bearing

**TrinaTracker R&D Department has gone a step further: the component, through its three-dimensional articulation, rather than two-dimensional axial movement, provided such significant added value, easing and lowing risk to the tracker installation that the company decided to patent the product.**

The first bearing design was cylindrical. In the first assembly of a test tracker, the problems of assembly and alignment became apparent.

Initially, all bearings were, and still are cylindrical; however, **TrinaTracker** R&D Department has gone a step further, and after analysing and testing the installation and operation of the trackers with bearings installed, the team discovered that there was still room for improvement.

When the R&D Department installed the cylindrical bearings in testing tracker samples, they identified specific issues related to the **assembly and alignment**, derived from the mechanical operation.

The use of cylindrical bearings meant adding an extra difficulty in the alignment of the trackers since they can overcome neither the bends of the poles nor the irregularities of the ground.

Alignment is a crucial process for **EPC companies** during the assembly process since the proper functioning of the tracker depends on a precise alignment.

**Image 4:** [illegible] installed in Habei, China, 400 MW

After the performance and testing of different bearings, **TrinaTracker** designed and implemented a spherical geometry for these elements. The component, through its **three-dimensional articulation**, rather than two-dimensional axial movement, provided such significant added value, easing and lowing risk to the tracker installation that the company decided to patent the product.

**Image 5:** [illegible] installed in Habei, China, 400 MW

| M [illegible] | N [illegible] | N [illegible] | | A [illegible] | D [illegible] | N [illegible] P [illegible] | C [illegible] | G [illegible] | D [illegible] |
|---|---|---|---|---|---|---|---|---|---|
| European Patent | EP2735817A3<br>EP2735817A2 | Swivel mount for solar tracker shafts | Granted | 22/11/2013 | 30/11/2020 | 9th annuity | F16C11/06; F24J2/52; F24J2/54; F16C23/04 | DE<br>IT<br>ES | |
| European Patent | EP2735817B1<br>EP2735817B8 | Soporte giratorio de ejes de seguidores solares<br>Swivel mount for solar tracker shafts | Granted | 22/11/2013 | 30/11/2020 | 8th | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**Table 1:** [illegible] patents

This **spherical bearing** design helps the alignment of the tracker, as it aligns itself. As a result, it **eases and reduces time of installation** for EPC companies (including reduction in civil works and cut and fill costs and risks) and improves the trackers' unimpeded operation in service.

Image 6: [illegible] assembled in [illegible] 2P

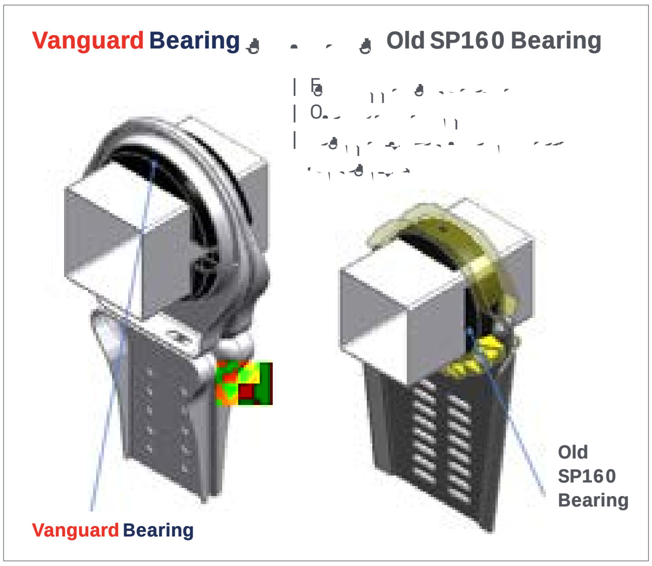



Image 7: Evolution of [illegible]

The new bearing design makes the joints more efficient; therefore, **maintenance is no required**.

The joint of the lower bearing support to the W post is designed with **circular holes** instead of slotted holes. This restricts movement associated with long term settlement and accordingly improves durability.

The component is made of UV stable and hard-wearing polyamide with fiberglass, which allows for the rotation axis to slide while **self-lubricating** when trackers move.

Since the adoption of this type of geometry, the **spherical bearing** became a critical element of the company's trackers. The bearing design has been in continuous **evolution and optimization**, adapting to the different characteristics of **TrinaTracker Agile 1P** and **Vanguard 2P** and innovating in materials, both in plastics and metallic housings.

The evolution of the bearing is going hand in hand with the development of the trackers, keeping up with the latest updates and optimization of the tracker industry in terms of **innovation leadership**.

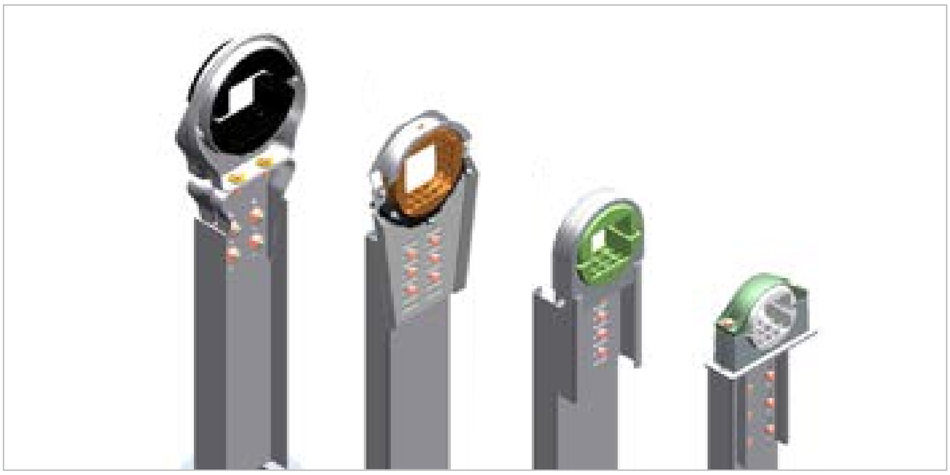


**Image 8:** Different [illegible] designs

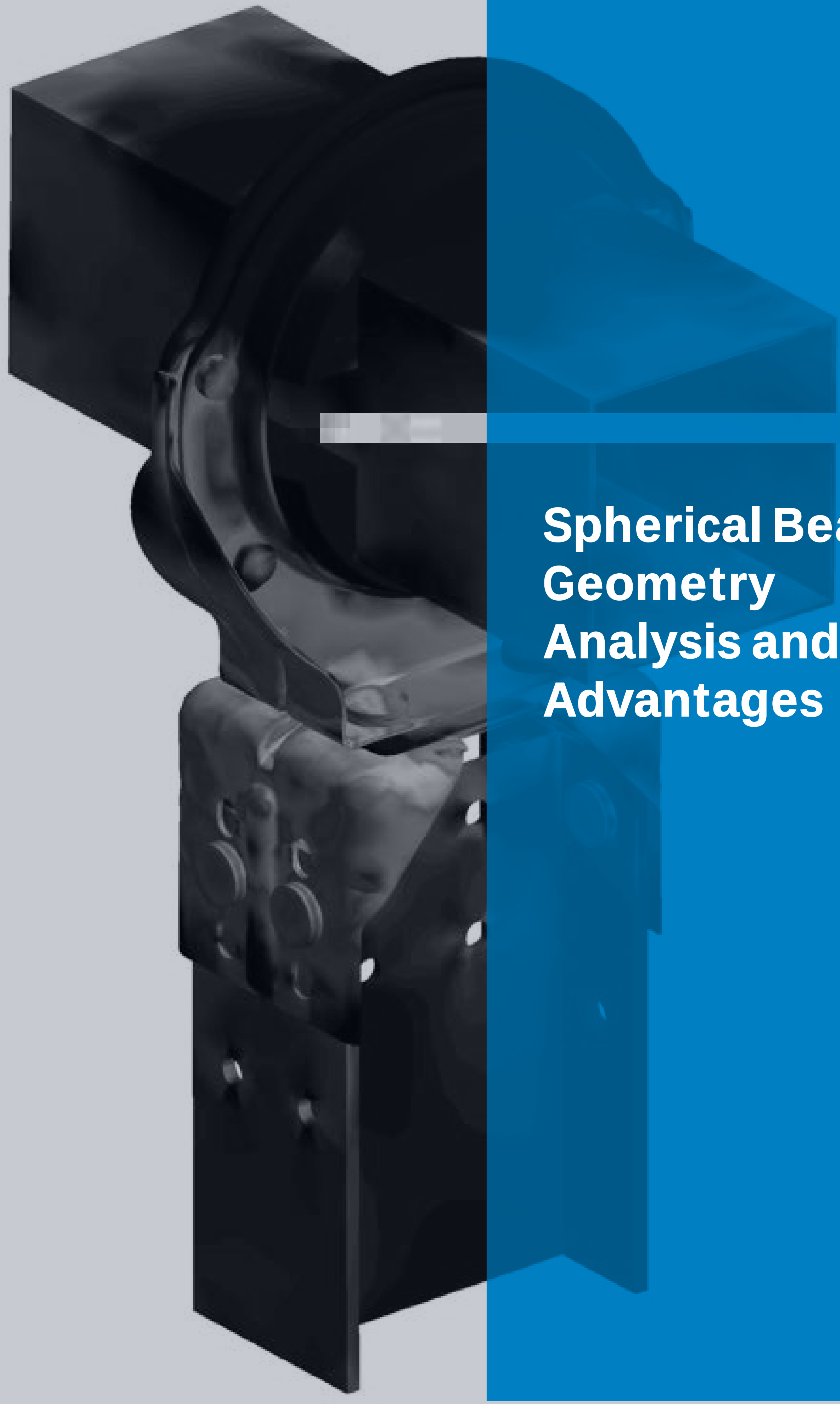
| Spherical bearing | Agile 1P | Vanguard 2P |
|---|---|---|
| **Housing material** | PA66+GF30 | S420GD |
| **Support material** | S420GD (excellent thermal performance & UV resistant) | |
| **Sphere** | POM (Excellent at self-lubrication, Hydrolysis resistance, stability of size in different temperatures, UV resistant) | |
| **Adaptability** | Designed to be installed in different type of piles | |
| **Assembly** | Flexible assembly (Split design) | Rigid assembly (robust design) |
| **Dimensions** | Adapted for 100, 120 mm torque tube | Adapted for 170 mm torque tube |
| **Designed for** | Tilted stow position and high horizontal loads | Extremely high mechanical strength |

**Table 2:** Differences between **Vanguard 2P** and **Agile 1P**´s [illegible]

TrinaTracker patented
**Spherical Bearing**

**Image 9:** **Agile 1P** [illegible]

**Image 10:** **Vanguard 2P** [illegible]



# 4

# Spherical Bearing Geometry Analysis and Advantages

# 4 Spherical Bearing Geometry Analysis and Advantages

**TrinaTracker** has patented the **spherical bearing**, and therefore, it is unique to the **Vanguard 2P** and **Agile 1P** series. The rest of the trackers available in the market employ cylindrical bearings.

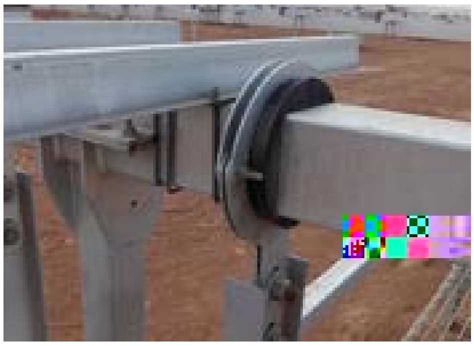


**Image 11 y 12:** Example of a commercial cylindrical bearing

The bearing structure is very simple at a first sight. It is comprised of two parts: the "housing," or fixed part, and the "Sphere" or moving part.

**TrinaTracker** patented **Spherical Bearing**

**Image 13:** Housing (fixed part)

**Image 14:** Sphere (moving part)

**TrinaTracker** patented **spherical bearings** can move around the three axes of rotation. This type of bearing has worked efficiently for **more than ten years** during the operation phase of trackers. The split feature of the bearing enables expedient installation of the torque tubes into the bearing assembly before the other bearing half and cap are assembled.

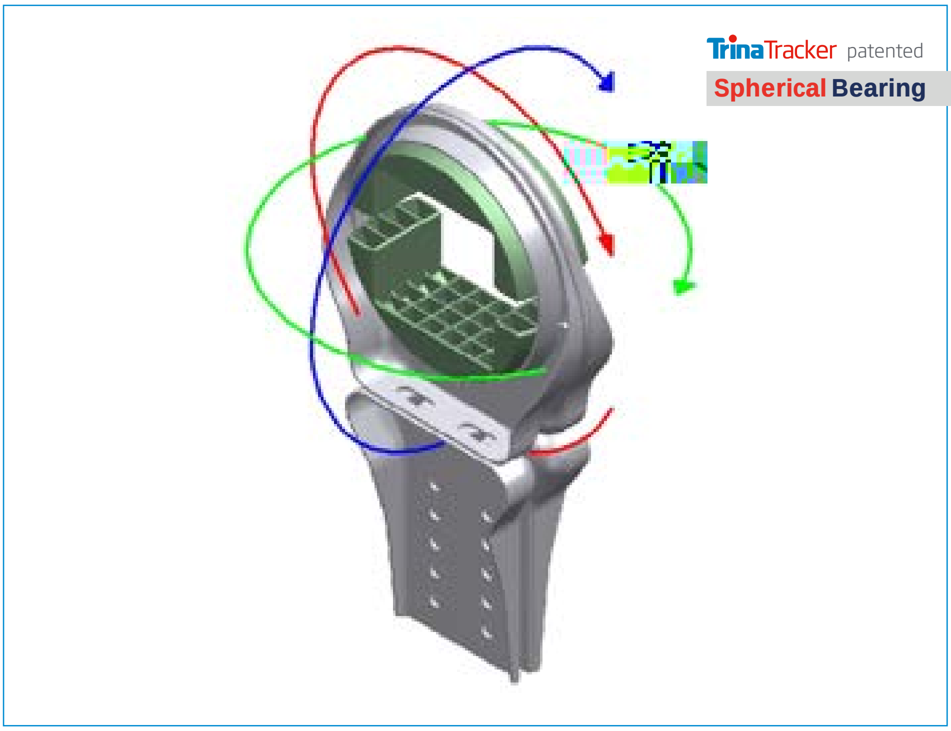
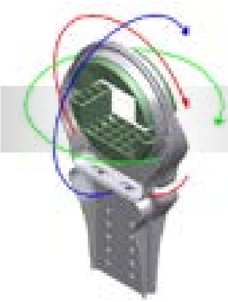



**Image 15:** Three-axis rotation



**TrinaTracker** patented

# Spherical Bearing

## The advantages of spherical bearings over cylindrical bearings are the following:

### 1 A [illegible]

The torsion in the “Z “ axis (longitudinal axis of the post) keeps the sphere inside the **spherical bearing** housing (cavity) and therefore maintains its ability to **rotate within tolerance**.

Installing cylindrical bearings would likely result in twisted posts. This effect is avoided by assembling **spherical bearings**.

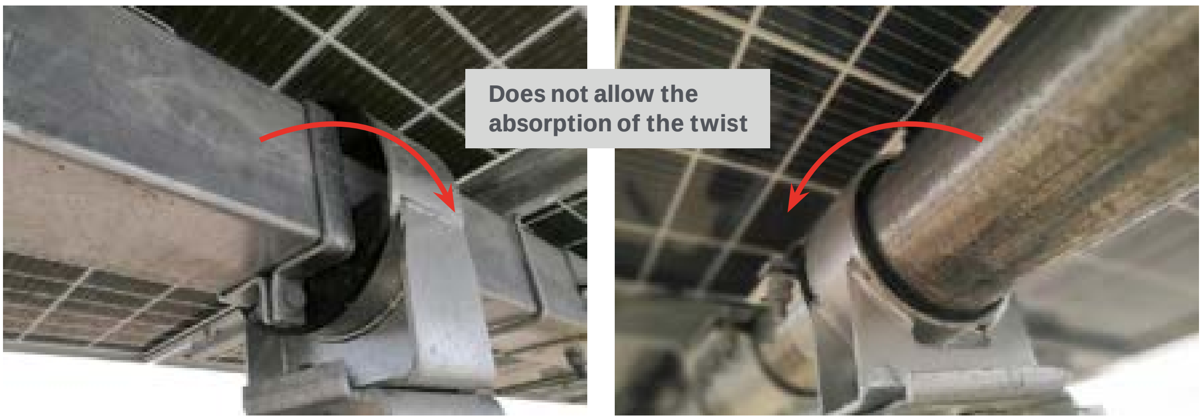



**Image 16:** Cylindrical bearing structure

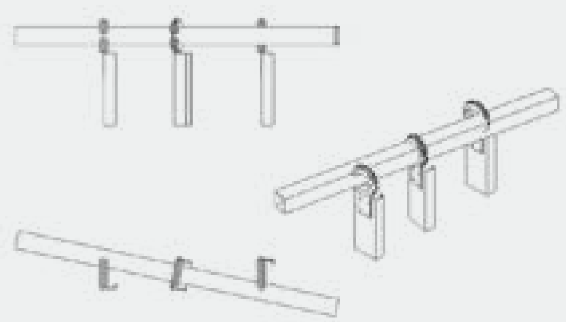


**Image 17:** Misalignment with cylindrical bearings on twisted post

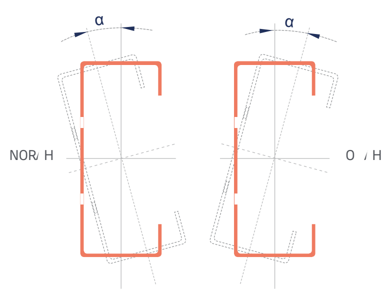



**Image 18:** Twist tolerance

## 2 A

In **uneven terrains**, the bearing geometry can rotate by itself requiring without making extra adjustments or adding elements to the bearing.

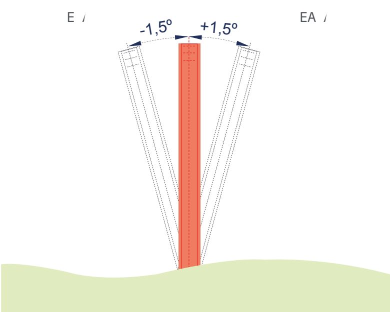



**Image 19:** Slope tolerance west-east

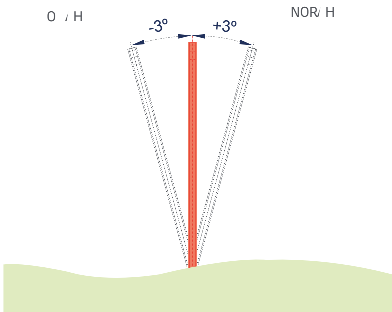



**Image 20:** Slope tolerance west-east

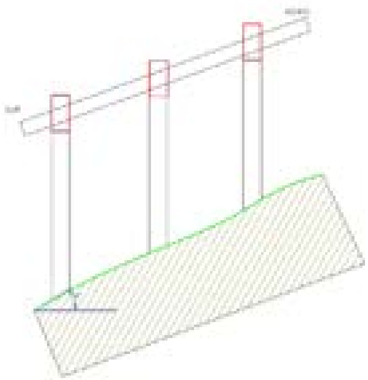


**Image 21:** installed in N-S slope

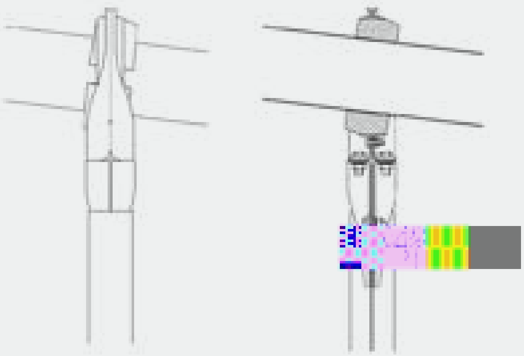


**Image 22:** performance when installed in N-S slope

Since the cylindrical bearings are typically larger, heavier, more difficult to mount, and require more substantive housings, they become disadvantageous when achieving perfect alignment.

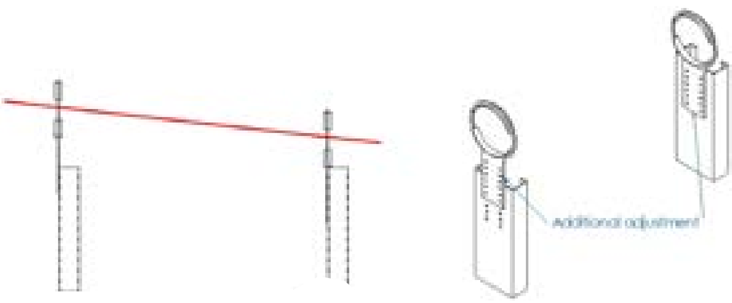


**Image 23:** Cylindrical bearing performance when installed in N-S slop

## 3 P[illegible]

The spherical geometry of the housing interface with the other spherical elements (the balls) prevents the latter from coming out of the bearing from disassembling itself during the operation.

**Image 24:** Front view of [illegible] cut in half

## 4 R[illegible]

This happens due to the same reason mentioned in the previous point.

## 5 [illegible]

Being **self-adjusting** eases the assembly process of the tracker.

**Image 25:** [illegible] installed in [illegible] 2P

## 6 [illegible] 50% [illegible]

The **spherical bearing** allows a reduction of at least **50 % of the assembly time** of each post, resulting in a considerable reduction of the overall installation time.

| Approximate data for assemblies | | |
|---|---|---|
| **Tracker Vanguard** | **Spherical** | **Cilindrical** |
| N[illegible] | 13 | 13 |
| [illegible] | 0.43 | 0.86 |
| [illegible] | 0 | 5.59 |
| [illegible] | 31.75 | 37.34 |
| [illegible] | 15% | |
| [illegible] M | 412.75 | 485.42 |
| [illegible] M [illegible] | 72.67 | |
| [illegible] | 9.08 | |

**Table 3:** Reduction of assembly time

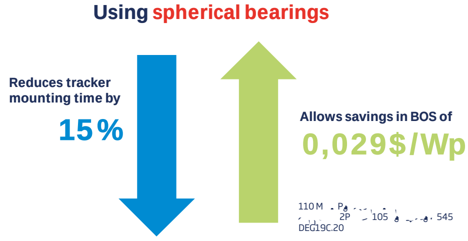
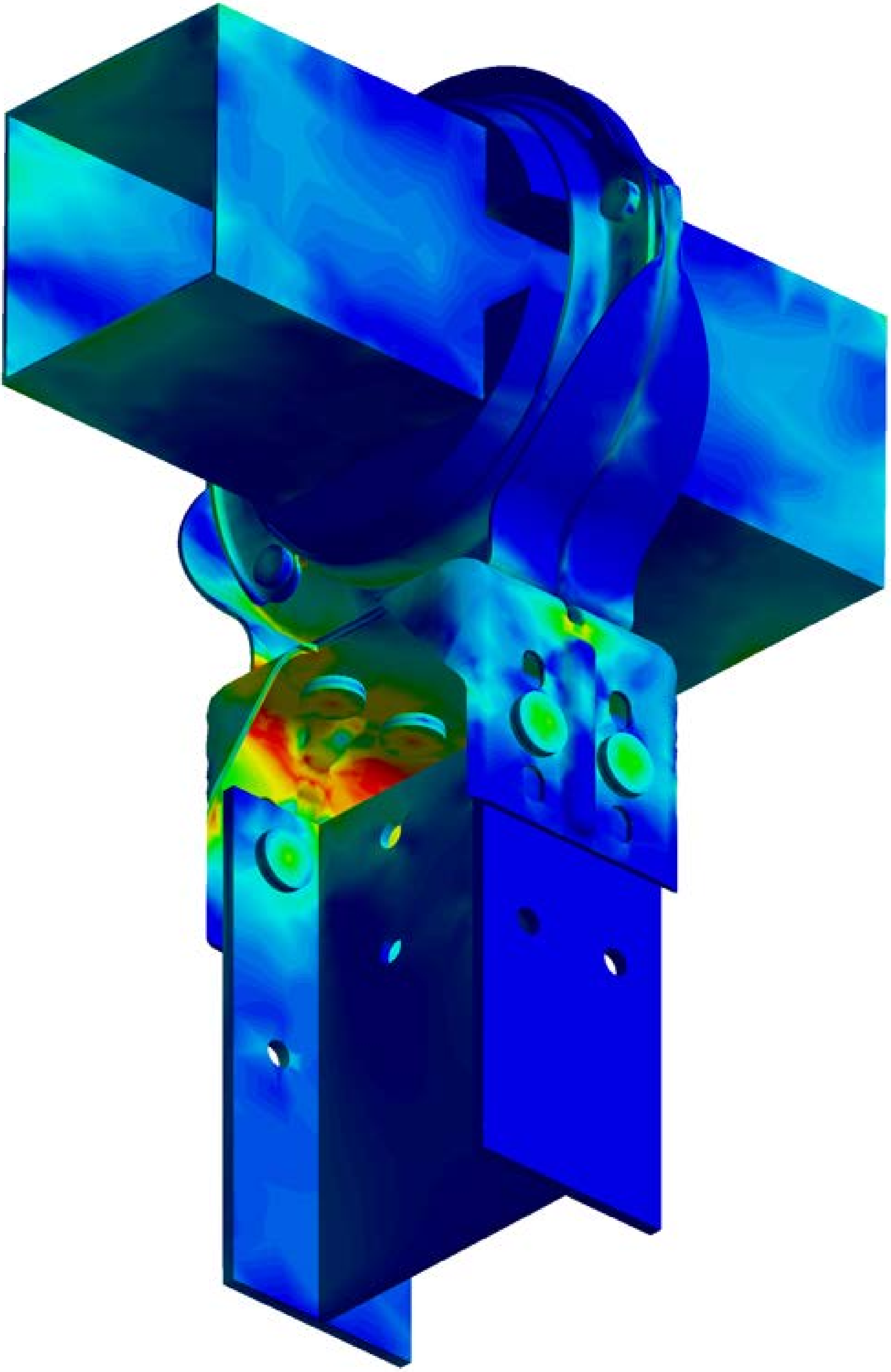



**Image 26:** Time and cost savings

Besides time reduction, **spherical bearings** also contribute to a lower LCOE. For example, when assembling **spherical bearings** instead of cylindrical bearings in a standard **TrinaTracker Vanguard 2P** tracker, the BOS cost is reduced by 0.029 $ per Wp and assembly times decrease by 15 %.



# 5 Materials

# 6

# Testing and Verification

6

# Testing and Verification

Each type of bearing is configured to withstand the maximum loads for which the tracker is designed.

The **maximum allowable** loads for bearings are evaluated and defined for subsequent projects by the R&D team.

The geometry of the bearings allows high resistance to radial loads (vertical and horizontal) and axial loads due to the ball's spherical shape.


**Video 3 :** Operation of

**FEM studies** are carried out on each model using the resulting loads to evaluate their structural adequacy under ultimate loads and optimize and check the geometry according to the plastic properties in the injection of the material.

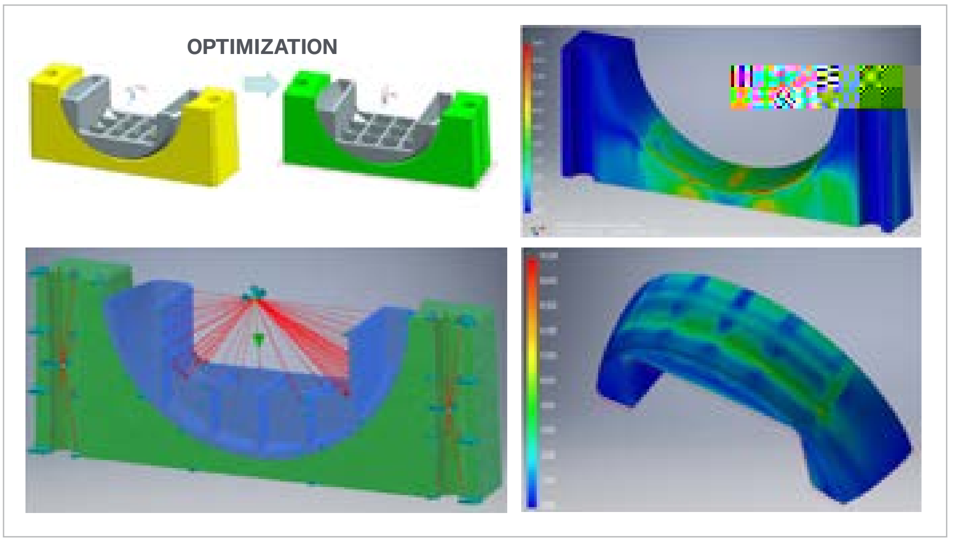



**Image 28:** Optimizing calculation of plastic part of bearing component

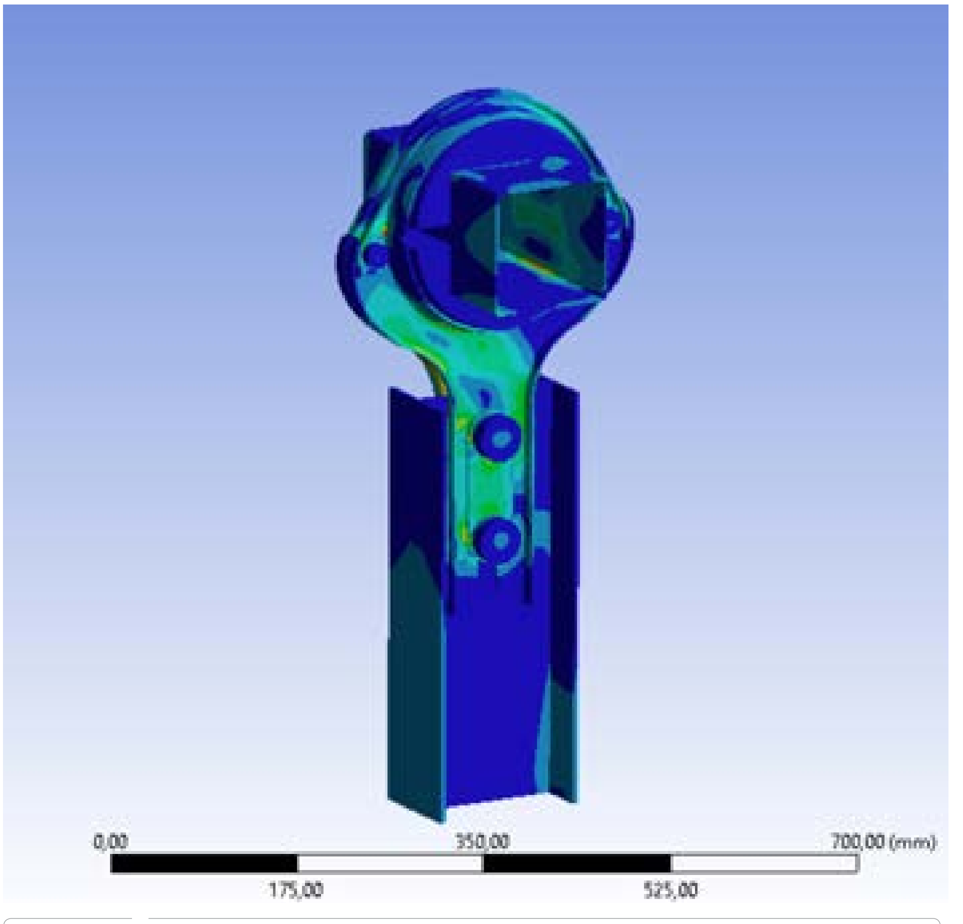



**Image 29:** FEM calculation sample

Load tests are performed at in-house **TrinaTracker** facilities or **specialized testing laboratories** to evaluate the maximum mechanical load to which the bearings can be subjected to.

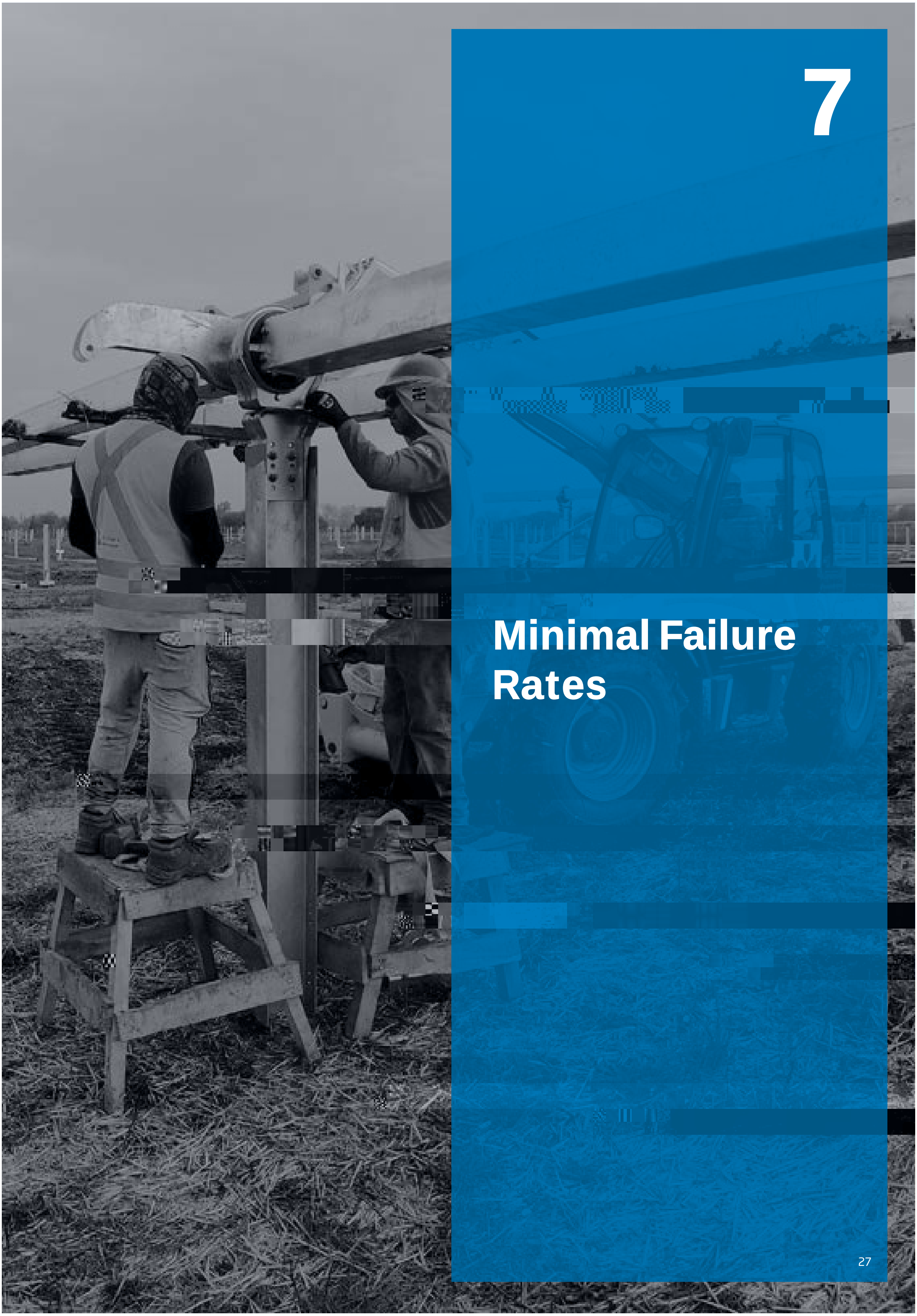
**Image 30:** testing

**Image 31:** testing


**Image 32:** testing


**Image 33:** testing

The tests are carried out following the EN1990: 2002. This regulation establishes a system of repetition of assessments to come at the resistance values of the union employing a statistical calculation.



# 7

# Minimal Failure Rates

# 7 Minimal Failure Rates

**Spherical bearings** report hardly any failure rate during the whole operation phase of the plant. Therefore, the installation of this component contributes to a reduction of operation and maintenance costs and tasks, **lowering LCOE** providing **higher ROI** to **TrinaTracker**'s clients.

The failure rates shown below are reported for **Agile 1P** and **Vanguard 2P***.

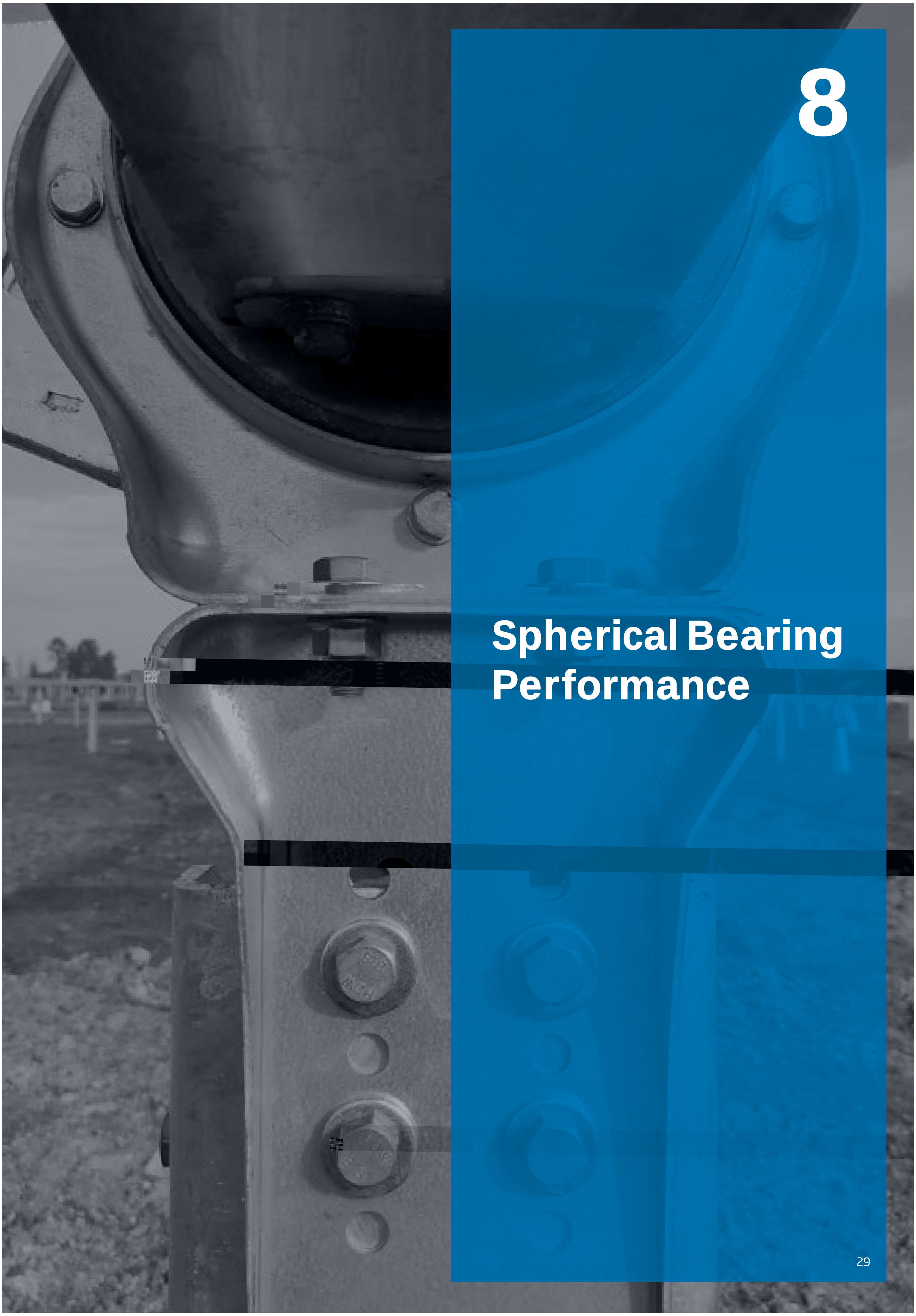
| [illegible] | [illegible] | [illegible] (N°) | 100 M[illegible] (N°) | R[illegible] ([illegible]) | R[illegible] ([illegible]) | F[illegible] R[illegible] (%) | O&M [illegible] ([illegible]) |
|---|---|---|---|---|---|---|---|
| 5 years | Bearing | 16.0 | 25.520 | 15 | 0.25 | 0.0250% | 1.60 |

**Table 4:** [illegible] failure rate in A[illegible] 1P

| [illegible] | [illegible] | [illegible] (N°) | 100 M[illegible] (N°) | R[illegible] ([illegible]) | R[illegible] ([illegible]) | F[illegible] R[illegible] (%) | O&M [illegible] ([illegible]) |
|---|---|---|---|---|---|---|---|
| 5 years | Bearing | 8.2 | 13.317 | 120 | 2.00 | 0.0250% | 6.66 |

**Table 5:** [illegible] failure rate in [illegible] 2P

* *Data gathered from* **TrinaTracker** *data base*



# 8

# Spherical Bearing Performance

8

# Spherical Bearing Performance

## Zuera 11 MW: Spherical bearings' excellent and long-lasting performance

**Zuera** is an 11MW PV plant installed in Zaragoza, Spain. Since its interconnection in 2008, no failure ratio has been reported, therefore the installation has become an example of **spherical bearings**' excellent and long-lasting performance.

It was in **Zuera** where the first **spherical bearings** were assembled in trackers, and nearly **one and a half decades** have passed with no instances of suboptimal actuation.

**Image 34:** [illegible] installed in Zuera 11 MW, Zaragoza

**Image 35:** Zuera 11 MW, Zaragoza

## Tongchuan, 30 MW: Spherical bearings' efficiency in uneven terrain

**Tongchuan** is a 250 MW plant installed in China. The project is divided into two parts: 30 MW with TrinaPro and 220MW with fixed tilt racking system.

Surrounding mountains decreased site accessibility to both construction crews and materials. The **undulated terrain** added one more challenge to the plant design and installation.

**TrinaTracker** employed adjustable bearing supporting structure along with flexible **spherical bearing** and reduced number of piles per tracker to alleviate construction complexity in this project, expediting the installation process.

**Tongchuan** project, which trackers have all spherical bearings assembled, achieve 3.5% better LCOE, brings 7.75% more generation output and 0.6% better IRR than fixed tilt structure. The results reinforce our confidence in our products and services for our customers worldwide.

**Image 36:** Tongchuan 250 MW, China

9

# Conclusions

# 9 Conclusions

**TrinaTracker** has always focused on **lowering risk and LCOE**, aiming its resources to continuously reduce product failure and achieve the highest and most assure long term energy outcome for our clients.

This is achieved by **TrinaTracker**'s **Research and Development Department** fanatical continually improvement of every element in the design of the company's trackers, both at component level and as holistic system upgrading every single one of its components, increasing the solar systems' reliability and decreasing failure rates precipitously.

This document aims to demonstrate the advantages of employing **spherical bearings** in place of cylindrical bearings by evaluating all possible load conditions in service. The benefits have been shown from different analyses and comparisons.

Some of the main advantages summarized in this document are:

**TrinaTracker** patented **Spherical Bearing**

- **Improved regulation on all tracker axes**
- **Self-alignment**
- **Elimination of the twist of the post and the fails on the driving**
- **Absorption of the slopes of the ground**
- **Reduction in civil cutting and terrain preparation costs**
- **Reduction of installation time**
- **Easing assembly time and facilitating assembly**
- **Decrease in costs arising from assembly rework**
- **Lack of bearing maintenance or adjustment during the lifetime of the PV plant**

As explained here, the bearing is one of the essential parts of the tracker, and **TrinaTracker** patented **spherical bearing** is recognized worldwide as industry leading.

Hundreds of customers and our own experience confirm these benefits.

**Images 37, 38 & 39:** [illegible] assembling example

# 10

# Competitive Advantages of TrinaTracker

# 10 Competitive Advantages of TrinaTracker

**TrinaTracker**, a business unit of **Trina Solar Ltd.** (SHA:688599), is a global solar tracker technology leader focused on providing "state-of-the-art" design solutions tailor-made to any terrain characteristics and weather conditions.

The company has more than 6GW of solar trackers deployed in 40 countries in which they accurately adapt the solar systems to each site's features. **TrinaTracker Agile 1P** and **Vanguard 2P** stand out in the market for their reliability, optimized design and minimal operation and maintenance requirements.

The trackers' compatibility with ultra-high power modules has been reported by **DNV**. Furthermore, **Agile 1P** and **Vanguard 2P** have been subjected to static, dynamic and aeroelastic loads through the most extensive tunnel test implemented in the solar industry and performed by leading wind engineering consultants, **CPP** and **RWDI**.

**TrinaTracker** is entirely focused on quality and innovation to provide its clients with high-technology solutions that achieve the highest energy yield and lowest **BOC** costs and **LCOE**.

## About Trina Solar

Founded in 1997, **Trina Solar** is the world-leading PV and smart energy total solution provider. The company engages in PV products R&D, manufacture and sales; PV projects development, EPC, O&M; smart micro-grid and multi-energy complementary systems development and sales; and energy cloud-platform operation.

In 2018, **Trina Solar** launched the Energy IoT brand, established the Trina Energy IoT Industrial Development Alliance and leading enterprises and research institutes in China and around the world and founded the New Energy IoT Industrial Innovation Center. With these actions, **Trina Solar** is committed to working with its partners to build the energy IoT ecosystem and develop an innovation platform to explore New Energy IoT, as it strives to be a leader in global intelligent energy. In June 2020, **Trina Solar** was listed on the STAR Market of the Shanghai Stock Exchange.

For more information, please visit **www.trinasolar.com**.

## Competitive Factors

**Own** R&D & Engineering Department

**Team** of more than **50** experienced and highly qualified engineers

**Consolidated expertise** in modelling, calculation and engineering design

**Extensive know-how** of solar industry technology and markets

**+6 GW** of plants where tracker design is tailor-made to meet the site characteristics and clients' requirements

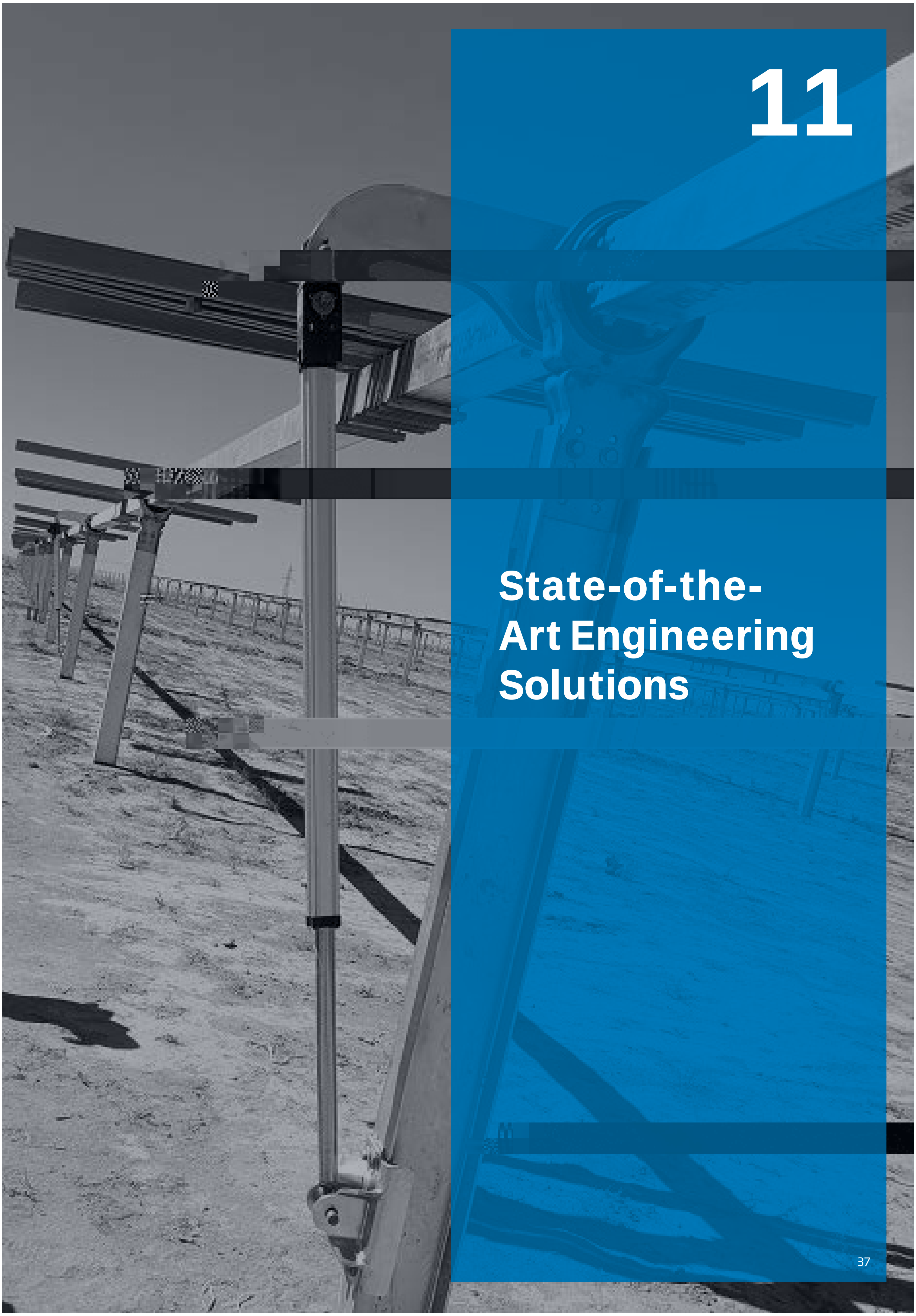
Trackers installed in more than **40 countries**

**In-house resources** to carry out geotechnical design, structural design, FEM analysis, physical testing, software and hardware design, detailed project design, research and development of products.

**Work partnership** with leading wind engineering consultancy companies (**RWDI** and **CPP**)

State-of-the-Art **engineering** design

Designed technology that complies with the highest **European and US standards** (IEC62817 and UL3703 Certifications respectively)



# 11

# State-of-the-Art Engineering Solutions

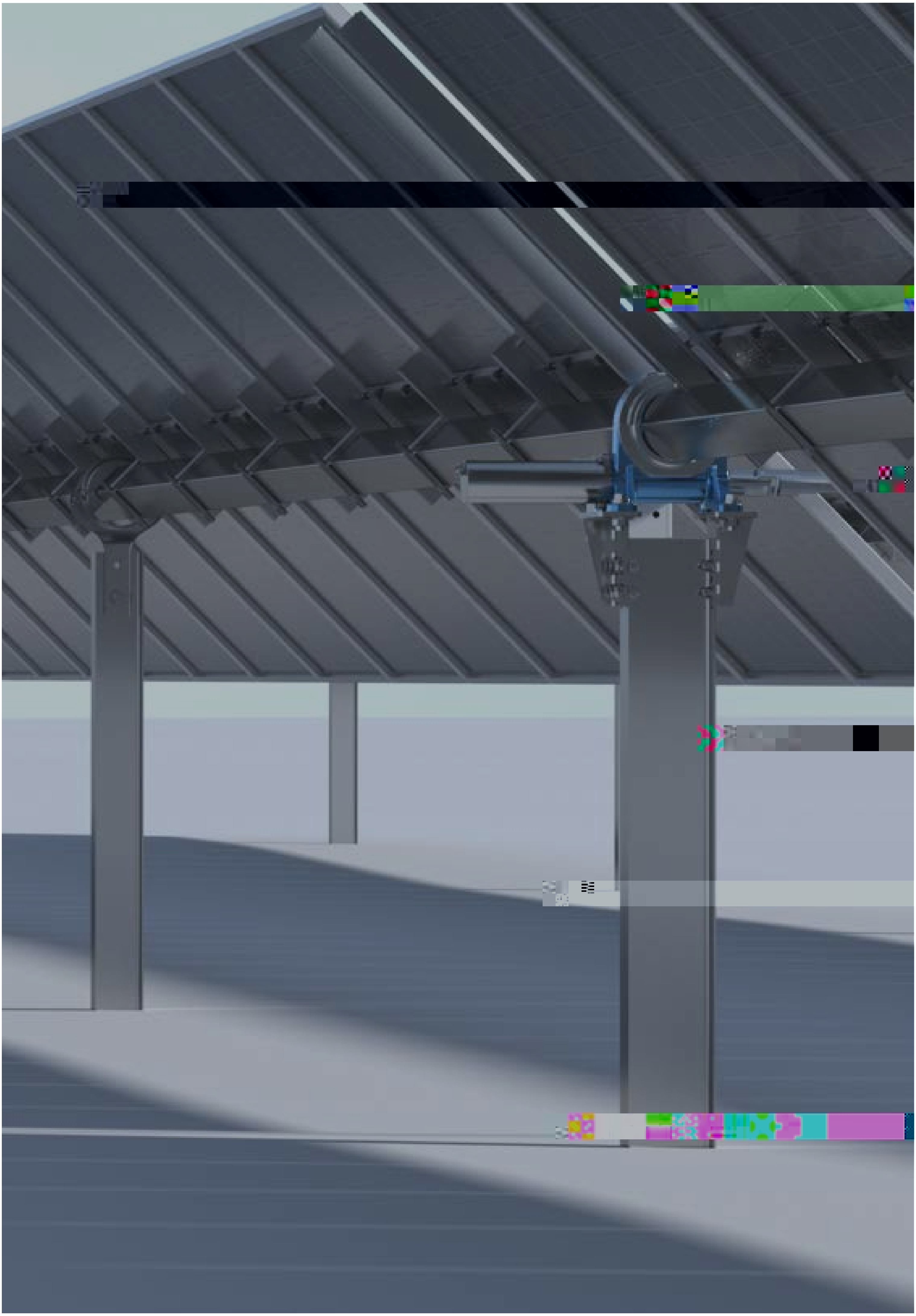
# 11 State-of-the-Art Engineering Solutions

## Vanguard™ 2P

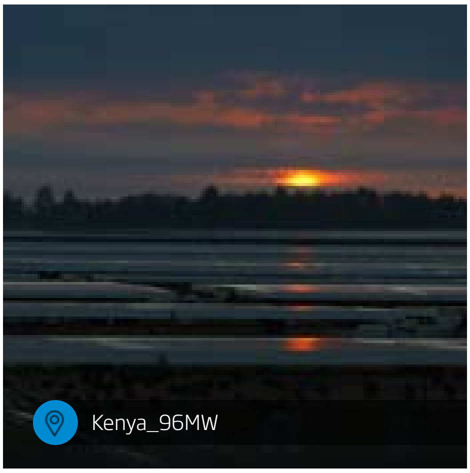
- 2P ... 210
- M...
- 120 ... 4 ...
- I ... E ...
- F ... 7 ... 120 ... M.
- G ... **Spherical Bearing** ... 30% ...
- **SuperTrack** ... 8%.

## Agile™ 1P

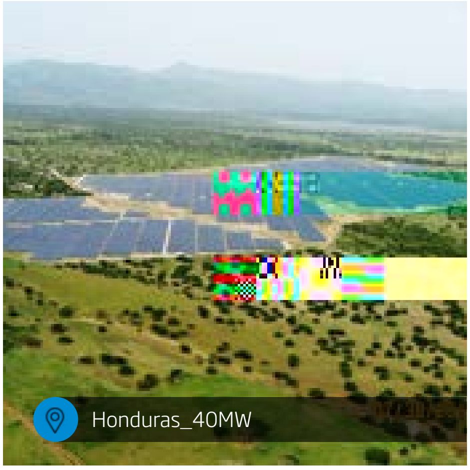
- I ... E ...
- 120 ... 4 ...
- D ... E ...
- O ...
- H ... 20% N/ , 10% E/ .
- **Trina Clamp** ...
- **SuperTrack** ... 8%.



# 12 +6 GW of Global Installations

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