Laser Tracker Application in the Hydro Industry: A Review of Current Trends and Future Prospects

Rajesh Kumar*, Aditya Narayan Bhatt**
*M-Tech Scholar (Production Technology) fromSanjeev Agarwal Global Educational (SAGE)UniversityBhopal
**Assistant Professor (SAGE UniversityBhopal)

Abstract:- Laser trackers have emerged as a powerful tool for accurate and precise measurement in a variety of industries, including hydro. We provide a comprehensive review of the current trends and future prospects of laser tracker applications in the hydro industry in this research paper. We begin by discussing the fundamentals of laser trackers, such as their operating principles and key features. We then look at the various applications of laser trackers in the hydro industry, such as dam monitoring, turbine alignment, as-built verification, and hydro component inspection. We examine the most recent advancements and innovations in laser tracker technology, such as increased accuracy, portability, and integration with other measurement tools. In addition, we discuss the advantages and disadvantages of using laser trackers in the hydro industry, such as increased efficiency, reduced downtime, and improved safety, as well as limitations such as environmental conditions, line of sight, and cost considerations.

Finally, we talk about the future of laser tracker applications in the hydro industry, including potential growth areas like digital twin technology, augmented reality, and automation. We conclude with research recommendations and emphasis the importance of laser trackers as a valuable tool for improving measurement accuracy and efficiency in the hydro industry.

Keywords:- *Laser tracker, hydro industry, dam monitoring, turbine alignment, as-built verification,component inspection, accuracy, portability, benefits, challenges, pre-assembly checks, and future prospects.*

I. INTRODUCTION

The hydro industry is critical to meeting the growing global demand for electricity by providing clean and renewable energy. Hydro facilities must be operated and maintained efficiently to ensure peak performance, minimize downtime, and maximize energy generation. Hydro components such as dams, turbines, and penstocks must be accurately measured and aligned for safe and reliable operation. Traditional measurement methods, such as manual surveying and alignment techniques, are time-consuming, labor-intensive, and prone to human error, resulting in inaccurate measurements and misalignments with significant safety and efficiency implications.

Laser trackers have gained popularity in recent years as a dependable and efficient tool for precise measurement in a variety of industries, including the hydro industry. Laser trackers have several advantages, including high accuracy, portability, and versatility, making them well-suited for a variety of hydro applications. We provide a comprehensive review of the current trends and future prospects of laser tracker applications in the hydro industry in this research paper, including their principles of operation, various applications, latest advancements, benefits, challenges, and future prospects.

II. FUNDAMENTALS OF LASER TRACKERS

Laser trackers are high-precision measurement instruments that use laser interferometry and angular encoders to determine the position and orientation of a retroreflective target in three dimensions (three dimensions). The basic operation involves the tracker head emitting a laser beam towards the target, which reflects the beam back to the tracker head. The tracker measures the laser beams round-trip time of flight, while the angular encoders measure the angles of the laser beam along two perpendicular axes. The tracker calculates the 3D position and orientation of the target relative to the tracker coordinate system with sub-millimeter accuracy by combining time-of-flight and angular measurements. Depending on the model and manufacturer, laser trackers typically have a working range of several meters to tens of meters and can measure targets that are in direct line of sight or hidden from direct line of sight using reflectors.

Laser trackers have a variety of features that improve their performance and versatility. One such feature is the ability to perform dynamic measurements, which allows for real-time tracking of moving targets during operation, such as rotating turbines. Another feature is the ability to measure in different reference frames, such as user-defined coordinate systems or coordinate systems defined by other measurement tools, such as total stations or GPS systems, allowing for seamless integration with existing measurement workflows. Laser trackers also include advanced software for data analysis, visualization, and reporting, making them an effective tool for measurement and alignment tasks in the hydro industry.

ISSN No:-2456-2165

III. FARO LASER TRACKER

Images 1: FARO Laser Tracker components pics

IV. HOW LASER TRACKERS OPERATE

A laser tracker's operation is straightforward: It takes two angles and a distance into account. A laser beam is sent by the tracker to a retro-reflective target that is held against the object to be measured. Light reflected off the target retraces its path and enters the tracker at the same point it left. The most common retro-reflective target is the spherically mounted retro-reflector (SMR). As light returns to the tracker, some of it is directed to a distance metre, which measures the distance between the tracker and the SMR. There are two types of distance metres: interferometers and absolute distance metres (ADMs).

Two angular encoders are found in a laser tracker. These instruments determine the angular orientation of the tracker's two mechanical axes: azimuth and elevation (or zenith). The encoder angles and distance from the distance metre are sufficient to precisely calculate the SMR centre. Because the SMR's spherical design places its centre at a fixed offset distance from any surface being measured, the coordinates of surfaces or points measured with the SMR are easily obtained. The laser tracker's distance measurement function can be either incremental or absolute. An interferometer and a frequency-stabilized helium-neon laser are used to measure incremental distance.

The laser light is separated into two beams. One enters the interferometer directly. The other beam exits the tracker, reflects off the SMR, and enters the interferometer on the way back. The two light beams interfere inside the interferometer, resulting in a cyclic change each time the SMR moves one quarter of the light's wavelength (0.0158 micron) closer or farther away from the tracker. To calculate the distance travelled, electronic circuitry counts the cyclic changes (known as "fringe counts").

Typically, the operator positions the SMR in the tracker's home position and resets the interferometer to the known (home) distance. The laser tracks along as the operator moves the SMR to the desired location, remaining fixed to the centre of the SMR. This procedure works well as long as the beam path from the tracker to the SMR is not interrupted by an obstruction. However, if the beam is broken, the number of counts is no longer valid and the distance is unknown. When this occurs, the tracker indicates an error has occurred. The SMR must then be returned to a reference point, such as the tracker's home position, by the operator.

Absolute distance measurement has been available for a long time. However, in the last ten years, ADM systems have advanced dramatically, providing accuracy comparable to interferometers.

The ability to simply point the beam at the target and shoot is an advantage of ADM measurement over incremental distance measurement. Even if the beam has previously been broken, the ADM system automatically measures the distance to the target. Infrared light from a semiconductor laser reflects off the SMR and re-enters the tracker, where it is converted into an electrical signal in an ADM tracker. The signal is analysed by electronic circuitry to determine its time of flight, which is then multiplied by the speed of light in air to determine the distance between the tracker and the SMR.

In the mid-1990s, absolute-distance metres first appeared in laser trackers. At the time, ADM units measured too slowly to allow for surface scanning. As a result, all early laser trackers had either an interferometer or an interferometer and an ADM. Some absolute-distance metres are now fast enough to allow for high-speed scanning with minimal accuracy loss. As a result, some modern trackers only have an ADM and no interferometer.

Beam steering and control is another tracker function. The laser beam is launched directly from the rotating structure of one type of tracker. Another type of tracker uses a rotating mirror to reflect a laser beam. In either case, by rotating the mechanical axes, the tracker directs the laser beam in the desired direction. The tracker keeps the beam centred on a rapidly moving SMR in many applications. This is accomplished by diverting a portion of the returning laser beam to a position-sensing detector (PSD). If the laser beam misses the SMR, the split-off beam misses the PSD as well, resulting in an error signal. This signal controls the rotation of the mechanical axes in order to keep the beam centred on the SMR.

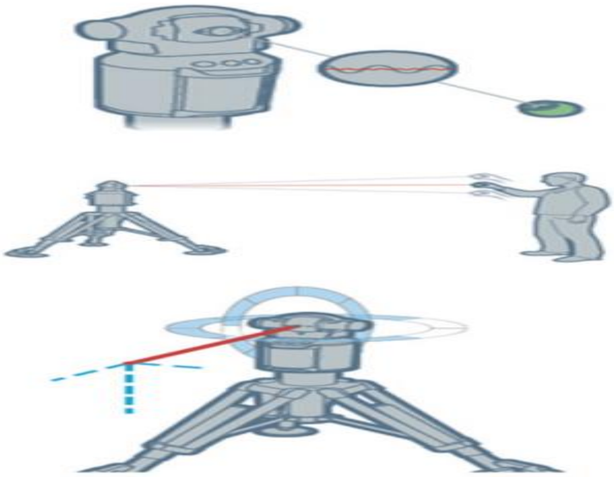


Image 2: Fundamental positions of Laser Trackers

V. APPLICATIONS OF LASER TRACKERS IN THE HYDRO INDUSTRY

In the hydro industry, where precise measurement and alignment are critical for safe and efficient operation, laser trackers have found a wide range of applications. Some of the most important applications of laser trackers in the hydro industry are as follows:

A. Dam Monitoring

Dams are critical infrastructure that must be monitored on a regular basis to ensure their stability and integrity. With high accuracy and repeatability, laser trackers can be used to monitor various dam parameters such as displacement, deformation, and settlement. Laser trackers can detect changes in the dam's shape or movement, which can indicate potential stability issues, by measuring the position of target points on the dam structure over time. Laser trackers can also be used to monitor the behavior of dam foundations and abutments during construction or rehabilitation projects, as well as to verify the as-built condition of dam components.

B. Turbine Alignment

The alignment of hydro turbines is critical for optimal performance and energy generation. Laser trackers can be used to precisely align the position and orientation of hydro turbines to sub-millimeter accuracy. Laser trackers can ensure precise alignment by measuring the position of target points on turbine components such as the rotor, stator, and guide vanes. Misalignments can result in energy losses, vibrations, and premature wear of turbine components. Laser trackers can also be used to perform dynamic alignment of rotating turbines while they are in operation, allowing for real-time adjustments to maintain optimal alignment and performance.

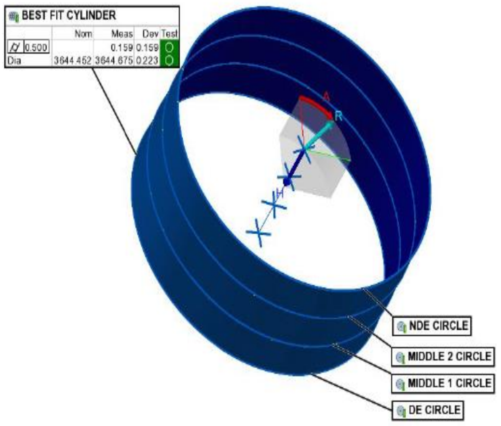
C. Verification of As-Built

Accurate verification of the as-built condition is required during the construction or rehabilitation of hydro facilities to ensure that the components are installed correctly and meet design specifications. Laser trackers can be used to compare the position, orientation, and dimensions of hydro components such as penstocks, gates, and spillways to design models or CAD data. Laser trackers can measure the as-built condition of these components quickly and accurately, allowing for timely adjustments or corrections to ensure compliance with design requirements and reduce rework.

D. Hydro Components Inspection

Hydro components, such as turbines, generators, and penstocks, must be inspected on a regular basis to detect potential problems and ensure their reliability and performance. With high accuracy and speed, laser trackers can inspect the position, shape, and dimensions of these components. Laser trackers can measure the geometrical features of these components, such as clearances, gaps, and misalignments, allowing for the early detection of problems that could lead to performance degradation or failure. Laser trackers can also be used to perform volumetric inspections on complex shapes such as turbine blades or generator rotors to detect any deformations or damages that could impair performance.

Dovetail Bar inner diameter measurement after welding in stator frame:



BEST FIT CYLINDER

Units	Millimeters
Coordinate Systems	ON BEST FIT
Data Alignments	original

Name	Control	Nom	Meas	Tol	Dev	Test	Out Tol
BEST FIT CYLINDER	⌭ 0.500		0.159	0.500	0.159	Pass	
	Diameter	3644.452	3644.675	+0.500/0.000	0.223	Pass	

NOTE:- ADD PROBE OFFSET 25.3 mm IN DIAMETER VALUE FOR ACTUAL READING AS IN THERMAL EXPANSION SHEET.

NOTE:- MEASUREMENT WAS TAKEN AT 28 DEG C

Image 3: Stator bar inner diameter measurement point

ALL CIRCLE DETAIL

Units	Millimeters
Coordinate Systems	ON BEST FIT
Data Alignments	original

Name	Control	Nom	Meas	Tol	Dev	Test	Out Tol
DE CIRCLE	○ 0.500		0.145	0.500	0.145	Pass	
	Diameter	3644.452	3644.637	+0.500/0.000	0.185	Pass	
MIDDLE 1 CIRCLE	○ 0.500		0.080	0.500	0.080	Pass	
	Diameter	3644.452	3644.710	+0.500/0.000	0.258	Pass	
MIDDLE 2 CIRCLE	○ 0.500		0.130	0.500	0.130	Pass	
	Diameter	3644.452	3644.686	+0.500/0.000	0.234	Pass	
NDE CIRCLE	○ 0.500		0.100	0.500	0.100	Pass	
	Diameter	3644.452	3644.710	+0.500/0.000	0.258	Pass	

NOTE:- ADD PROBE OFFSET 25.3 mm IN DIAMETER VALUE FOR ACTUAL READING AS IN THERMAL EXPANSION SHEET.

NOTE:- MEASUREMENT WAS TAKEN AT 28 DEG C

Image 4: Stator bar inner diameter fixing dimensions at all circle readings

DE POINT DETAIL

Units Millimeters

Name	Control	Nom	Meas	Tol	Dev	Test	Out Tol
• DE-1	R	1822.226	1822.342	+0.250/0.000	0.116	Pass	
• DE-2	R	1822.226	1822.306	+0.250/0.000	0.080	Pass	
• DE-3	R	1822.226	1822.316	+0.250/0.000	0.090	Pass	
• DE-4	R	1822.226	1822.297	+0.250/0.000	0.071	Pass	
• DE-5	R	1822.226	1822.249	+0.250/0.000	0.023	Pass	
• DE-6	R	1822.226	1822.347	+0.250/0.000	0.121	Pass	
• DE-7	R	1822.226	1822.236	+0.250/0.000	0.010	Pass	
• DE-8	R	1822.226	1822.382	+0.250/0.000	0.156	Pass	
• DE-9	R	1822.226	1822.347	+0.250/0.000	0.121	Pass	
• DE-10	R	1822.226	1822.237	+0.250/0.000	0.011	Pass	
• DE-11	R	1822.226	1822.340	+0.250/0.000	0.114	Pass	
• DE-12	R	1822.226	1822.265	+0.250/0.000	0.039	Pass	
• DE-13	R	1822.226	1822.307	+0.250/0.000	0.081	Pass	
• DE-14	R	1822.226	1822.268	+0.250/0.000	0.042	Pass	
• DE-15	R	1822.226	1822.304	+0.250/0.000	0.078	Pass	
• DE-16	R	1822.226	1822.311	+0.250/0.000	0.085	Pass	
• DE-17	R	1822.226	1822.256	+0.250/0.000	0.030	Pass	
• DE-18	R	1822.226	1822.396	+0.250/0.000	0.170	Pass	
• DE-19	R	1822.226	1822.277	+0.250/0.000	0.051	Pass	
• DE-20	R	1822.226	1822.359	+0.250/0.000	0.133	Pass	
• DE-21	R	1822.226	1822.257	+0.250/0.000	0.031	Pass	
• DE-22	R	1822.226	1822.387	+0.250/0.000	0.161	Pass	
• DE-23	R	1822.226	1822.327	+0.250/0.000	0.101	Pass	
• DE-24	R	1822.226	1822.389	+0.250/0.000	0.163	Pass	

NOTE:- ADD PROBE OFFSET 12.65 mm IN RADIUS VALUE FOR ACTUAL READING AS IN THERMAL EXPANSION SHEET.

NOTE:- MEASUREMENT WAS TAKEN AT 28 DEG C

Image 5: Stator bar inner diameter fixing dimensions at DE side readings

MIDDLE-1 POINT DETAIL

Units Millimeters

Name	Control	Nom	Meas	Tol	Dev	Test	Out Tol
• MIDDLE _1-1	R	1822.226	1822.308	+0.250/0.000	0.082	Pass	
• MIDDLE _1-2	R	1822.226	1822.362	+0.250/0.000	0.136	Pass	
• MIDDLE _1-3	R	1822.226	1822.243	+0.250/0.000	0.017	Pass	
• MIDDLE _1-4	R	1822.226	1822.365	+0.250/0.000	0.139	Pass	
• MIDDLE _1-5	R	1822.226	1822.315	+0.250/0.000	0.089	Pass	
• MIDDLE _1-6	R	1822.226	1822.401	+0.250/0.000	0.175	Pass	
• MIDDLE _1-7	R	1822.226	1822.392	+0.250/0.000	0.166	Pass	
• MIDDLE _1-8	R	1822.226	1822.327	+0.250/0.000	0.101	Pass	
• MIDDLE _1-9	R	1822.226	1822.394	+0.250/0.000	0.168	Pass	
• MIDDLE _1-10	R	1822.226	1822.393	+0.250/0.000	0.167	Pass	
• MIDDLE _1-11	R	1822.226	1822.379	+0.250/0.000	0.153	Pass	
• MIDDLE _1-12	R	1822.226	1822.325	+0.250/0.000	0.099	Pass	
• MIDDLE _1-13	R	1822.226	1822.340	+0.250/0.000	0.114	Pass	
• MIDDLE _1-14	R	1822.226	1822.330	+0.250/0.000	0.104	Pass	
• MIDDLE _1-15	R	1822.226	1822.344	+0.250/0.000	0.118	Pass	
• MIDDLE _1-16	R	1822.226	1822.363	+0.250/0.000	0.137	Pass	
• MIDDLE _1-17	R	1822.226	1822.371	+0.250/0.000	0.145	Pass	
• MIDDLE _1-18	R	1822.226	1822.375	+0.250/0.000	0.149	Pass	
• MIDDLE _1-19	R	1822.226	1822.314	+0.250/0.000	0.088	Pass	
• MIDDLE _1-20	R	1822.226	1822.352	+0.250/0.000	0.126	Pass	
• MIDDLE _1-21	R	1822.226	1822.336	+0.250/0.000	0.110	Pass	
• MIDDLE _1-22	R	1822.226	1822.374	+0.250/0.000	0.148	Pass	
• MIDDLE _1-23	R	1822.226	1822.319	+0.250/0.000	0.093	Pass	
• MIDDLE _1-24	R	1822.226	1822.373	+0.250/0.000	0.147	Pass	

NOTE:- ADD PROBE OFFSET 12.65 mm IN RADIUS VALUE FOR ACTUAL READING AS IN THERMAL EXPANSION SHEET.

NOTE:- MEASUREMENT WAS TAKEN AT 28 DEG C

Image 6: Stator bar inner diameter fixing dimensions at middle readings

NDE POINT DETAIL

Units Millimeters

Name	Control	Nom	Meas	Tol	Dev	Test	Out Tol
NDE-1	R	1822.226	1822.338	+0.250/0.000	0.112	Pass	
NDE-2	R	1822.226	1822.347	+0.250/0.000	0.121	Pass	
NDE-3	R	1822.226	1822.335	+0.250/0.000	0.109	Pass	
NDE-4	R	1822.226	1822.388	+0.250/0.000	0.162	Pass	
NDE-5	R	1822.226	1822.388	+0.250/0.000	0.162	Pass	
NDE-6	R	1822.226	1822.336	+0.250/0.000	0.110	Pass	
NDE-7	R	1822.226	1822.249	+0.250/0.000	0.023	Pass	
NDE-8	R	1822.226	1822.335	+0.250/0.000	0.109	Pass	
NDE-9	R	1822.226	1822.398	+0.250/0.000	0.172	Pass	
NDE-10	R	1822.226	1822.342	+0.250/0.000	0.116	Pass	
NDE-11	R	1822.226	1822.371	+0.250/0.000	0.145	Pass	
NDE-12	R	1822.226	1822.294	+0.250/0.000	0.068	Pass	
NDE-13	R	1822.226	1822.393	+0.250/0.000	0.167	Pass	
NDE-14	R	1822.226	1822.373	+0.250/0.000	0.147	Pass	
NDE-15	R	1822.226	1822.349	+0.250/0.000	0.123	Pass	
NDE-16	R	1822.226	1822.357	+0.250/0.000	0.131	Pass	
NDE-17	R	1822.226	1822.377	+0.250/0.000	0.151	Pass	
NDE-18	R	1822.226	1822.350	+0.250/0.000	0.124	Pass	
NDE-19	R	1822.226	1822.306	+0.250/0.000	0.080	Pass	
NDE-20	R	1822.226	1822.340	+0.250/0.000	0.114	Pass	
NDE-21	R	1822.226	1822.352	+0.250/0.000	0.126	Pass	
NDE-22	R	1822.226	1822.402	+0.250/0.000	0.176	Pass	
NDE-23	R	1822.226	1822.325	+0.250/0.000	0.099	Pass	
NDE-24	R	1822.226	1822.336	+0.250/0.000	0.110	Pass	

NOTE:- ADD PROBE OFFSET 12.65 mm IN RADIUS VALUE FOR ACTUAL READING AS IN THERMAL EXPANSION SHEET.

NOTE:- MEASUREMENT WAS TAKEN AT 28 DEG C

Image 7: Stator bar inner diameter fixing dimensions at NDE side readings

VI. FINAL RESULTS

20	1834.7	1834.7	3669.4
21	1834.722	1834.7	3669.444
22	1834.744	1834.7	3669.488
23	1834.766	1834.7	3669.532
24	1834.788	1834.7	3669.576
25	1834.81	1834.7	3669.62
26	1834.832	1834.7	3669.664
27	1834.854	1834.7	3669.708
28	1834.876	1834.7	3669.752
29	1834.898	1834.7	3669.796
30	1834.92	1834.7	3669.84
31	1834.942	1834.7	3669.884
32	1834.964	1834.7	3669.928
33	1834.986	1834.7	3669.972
34	1835.008	1834.7	3670.016
35	1835.03	1834.7	3670.06
36	1835.052	1834.7	3670.105

NOTE:-

Measurement is taken at 28 deg C Temp.

Nominal Radius at 28 deg C is 1834.876 mm

Now remove the probe offset 12.65 mm from given Nominal.

So, it will be Radius 1834.876 - 12.65 =1822.226 mm

So by that I entered radius 1822.226 mm as a nominal in the Measurement Data

So by that I entered diameter 3644.452 mm as a nominal in the Measurement Data

Image 8: Stator bar inner diameter fixing final readings

VII. LATEST LASER TRACKER TECHNOLOGY ADVANCEMENTS

In recent years, laser tracker technology has advanced rapidly, resulting in significant improvements in accuracy, portability, and integration with other measurement tools. Some of the most recent advances in laser tracker technology with potential applications in the hydro industry are as follows:

- **Increased Precision -** Accuracy is critical in hydro industry measurement and alignment tasks. Recent advances in laser tracker technology have improved accuracy, with some trackers capable of sub-millimeter accuracy over long distances. This increased precision enables more precise and dependable measurements, lowering the margin of error in critical alignment and inspection tasks. Improved accuracy also allows laser trackers to be used in applications requiring high precision, such as monitoring small deformations or inspecting intricate components.
- **Enhanced Portability -**Another important factor in the hydro industry is portability, as measurement and alignment tasks may need to be performed in remote or difficult environments. Recent advances in laser tracker technology have resulted in more portable and lightweight trackers that are easier to transport and set up in different locations. Some laser trackers are now battery-powered, allowing for cordless operation, removing the need for external power sources and increasing their field versatility. Increased portability allows laser trackers to be used in applications that require mobility and flexibility, such as dam monitoring in remote locations or turbine alignment in confined spaces.
- **Integration with Other Measuring Instruments-** To provide comprehensive measurement and alignment solutions, laser trackers can be combined with other measurement tools such as total stations, GPS systems, and 3D scanners. Laser tracker technology advancements have made it easier to integrate with other measurement tools, allowing for seamless data exchange and integration of different measurement techniques. Laser trackers, for example, can be used in conjunction with total stations to measure targets that are not in the tracker's line of sight, or with 3D scanners to capture detailed surface information for inspection tasks. Integration with other measurement tools expands laser trackers' versatility and capabilities, making them a more powerful tool for hydro industry applications.
- **Capabilities of Advanced Software-** Laser trackers include advanced software that allows for data analysis, visualization, and reporting, making them a complete solution for measurement and alignment tasks. Recent software advancements have resulted in more user-friendly interfaces, improved data processing algorithms, and enhanced reporting capabilities. Some laser trackers now include cloud-based software that enables remote data access and analysis, facilitating team collaboration and data sharing. Advanced software capabilities allow for more efficient data processing, analysis, and reporting, reducing the time and effort required for hydro industry measurement and alignment tasks.

VIII. CHALLENGES AND PROSPECTS FOR THE FUTURE

Despite significant advances in laser tracker technology, there are still some challenges and limitations to overcome. Some of the difficulties associated with the use of laser trackers in the hydro industry are as follows:

A. Environmental Factors

Working in the hydro industry frequently entails working in difficult environmental conditions such as high humidity, extreme temperatures, and water splashes. Because laser trackers rely on line-of-sight measurements, which can be influenced by atmospheric conditions or water droplets on the reflectors, these conditions can have an impact on their performance and accuracy. To address these issues, some laser trackers include environmental protection features such as dust and water resistance. However, more research and development are required to improve laser tracker performance in challenging environmental conditions, ensuring their reliability and accuracy in hydro industry applications.

B. Cost and Accessibility

Laser trackers are sophisticated, high-precision instruments that can be costly in comparison to other measurement tools. The cost of laser trackers may be prohibitively expensive for small and medium-sized hydro facilities with limited resources. Furthermore, the availability of skilled operators trained to operate and interpret data from laser trackers may be limited, limiting the accessibility and utilization of this technology in the hydro industry. It is expected that as laser tracker technology advances, the cost will fall, and training and education programs will be developed to improve the accessibility and utilization of laser trackers in the hydro industry.

C. Workflow Integration with Existing Workflows

Integrating laser trackers into existing measurement workflows in the hydro industry may necessitate changes or adjustments to existing processes, which can be difficult. Integrating laser trackers, for example, with other measurement tools or software may necessitate additional training and changes in data processing procedures. Coordination and management of data from various sources, as well as ensuring data consistency and accuracy throughout the measurement and alignmenttasks, may presentchallenges. Overcoming these challenges may necessitate close collaboration between laser tracker manufacturers, hydro industry professionals, and software developers in order to develop seamless integration solutions that fit into existing hydro industry workflows and processes.

D. Certification and standardization

Another barrier to the use of laser trackers in the hydro industry is a lack of standardized procedures and certification requirements. There are currently no universal standards or certifications designed specifically for laser tracker measurements in the hydro industry. This can make it difficult to ensure consistent and reliable measurement results across multiple projects and facilities. The standardization of measurement procedures, data analysis methods, and reporting requirements can aid in the improvement of the accuracy and comparability of laser tracker measurements in the hydro industry. Collaboration among industry professionals, regulatory bodies, and laser tracker manufacturers can help to develop standardized procedures and certifications for the use of laser trackers in the hydro industry.

Despite these obstacles, the future of laser tracker applications in the hydro industry looks bright. Laser tracker technology is expected to advance further, with improvements in accuracy, portability, integration with other measurement tools, and software capabilities. The hydro industry is likely to see greater adoption of the technology as it becomes more accessible and cost-effective. Furthermore, greater awareness and education about the advantages of laser trackers for measurement and alignment tasks in the hydro industry can lead to greater acceptance and utilization of this technology. Collaboration among industry professionals, researchers, and manufacturers has the potential to drive further innovation and development in the field of laser tracker application in the hydro industry.

IX. CONCLUSION

Finally, laser trackers have emerged as a versatile and powerful tool for hydro industry measurement and alignment tasks. They are well-suited for a variety of applications, including dam monitoring, turbine alignment, and equipment installation, due to their high accuracy, portability, integration capabilities, and advanced software functionalities. In terms of accuracy, efficiency, and flexibility, laser trackers outperform traditional measurement methods. However, challenges such as environmental conditions, cost and accessibility, integration with existing workflows, and standardization and certification must be addressed. Genuine model involves gradually replacing the traditional installation method with an electronic" installation" structure.

As laser tracker technology advances and becomes more affordable, it has enormous potential for improving measurement and alignment tasks in the hydro industry. Collaboration between industry professionals, researchers, and manufacturers can be critical in driving innovation and development in this field. Procedure standardization, certification requirements, and training programs can all help to ensure consistent and reliable measurement results. More research and development is required to address the challenges and fully realize the potential of laser trackers in the hydro industry.

Overall, laser tracker application in the hydro industry is a rapidly evolving field, with current trends indicating significant technological advancements and promising future prospects. Laser trackers are expected to play an increasingly important role in improving measurement and alignment tasks in the hydro industry, contributing to increased efficiency, accuracy, and safety in hydro facility operations. To fully exploit the potential of laser trackers in the hydro industry and unlock new opportunities for improved performance and productivity in this critical sector, additional research, collaboration, and standardization efforts are required.

ACKNOWLEDGEMENTS

The authors would like to thank all of the researchers, professionals, and organizations who have contributed to the field of laser tracker application in the hydro industry. Their contributions and insights have aided in the understanding of current trends and future prospects for this technology. The authors also thank their respective institutions for their assistance and guidance in conducting this research.

REFERENCES

[1.] Balouet, J. C., & Touzon, P. (2018). 3D Laser Tracker for High Accuracy Measurements in Hydro Power Plants. World Water Congress and Exhibition 2018, 3336-3346.

[2.] GAO, J., Sun, H., & Zhu, X. (2018).Research on the Application of Laser Tracker in Hydraulic Turbine Alignment. IOP Conference Series: Earth and Environmental Science, 158(2), 022030.

[3.] Huang, Q., Sun, H., & Wang, B. (2019). Research on Key Technology of Dam Deformation Monitoring Based on Laser Tracker. IOP Conference Series: Earth and Environmental Science, 253(4), 042053.

[4.] Keller, D., & Kolleck, R. (2016). New Solutions for Hydro Turbine Alignment using Laser Trackers. International Journal of Hydroelectric Energy, 34(2), 106-113.

[5.] Kolleck, R., & Viciano, J. (2014). The use of laser trackers in the alignment of large hydropower units. Hydro Review Worldwide, 22(4), 34-39.

[6.] Kreth, G. (2019). The application of the Laser Tracker for hydro turbine alignment - project results. In Proceedings of the ASME 2019 Power Conference, Volume 1: Fuels, Combustion, and Material Handling; Solar, Wind, and Geothermal Energy; Environmental and Regulations; Energy Policy, Economics, and Sustainability; Hydrogen Production, Storage, and Transportation; Hydroelectric Power; Thermal Hydraulics and CFD; Nuclear Systems and Technologies; Transmission and Grid Applications (pp. V001T06A001-V001T06A001). American Society of Mechanical Engineers.

[7.] Laser Technology, Inc. (2018). How Laser Trackers are Revolutionizing Hydro Turbine Alignment. Retrieved from https://www.lasertech.com/How-Laser-Trackers-are-Revolutionizing-Hydro-Turbine-Alignment

[8.] Leica Geosystems AG. (2019). Leica Absolute Tracker AT930/AT960. Retrieved from https://leica-geosystems.com/products/laser-tracker-software/leica-absolute-tracker-at930-at960

[9.] Leica Geosystems AG. (2020). Metrology Services - Industrial Measurement Services. Retrieved from https://leica-geosystems.com/products/metrology-services

ISSN No:-2456-2165

[10.] Rahn, M. (2016). Hydro turbine alignment: getting it right. World Dams, 104, 31-33.
[11.] Rosell, J. L., & Gomis, P. (2018). Three-dimensional measurement and alignment of hydraulic turbines using laser trackers. Journal of Mechanical Science and Technology, 32(3), 1407-1415.
[12.] Uddin, A., & Wan, F. (2018). Recent Advances in Laser Tracking Technology: A Review. Sensors, 18(5), 1396.
[13.] Zeiss Industrial Metrology. (2019). T-SCAN LV: Fast Scanning with T-TRACK LV. Retrieved from https://www.zeiss.com/metrology/products/systems/laser-scanner/t-scan-lv.html
[14.] https://www.researchgate.net/publication/349983701_Application_of_laser_tracker_in_the_industrial_measurement_field
[15.] A Survey of Current Robot Metrology Methods
[16.] https://doi.org/10.1016/S0007-8506(16)30170-6