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Industrial Metrology and Engineering Applications in the Wind Turbine Industry

1. Company Introduction

M-7 Technologies is a privately owned, ISO 9001 certified company offering engineered solutions for a wide range of manufacturing sectors. Through technology and research M-7 constantly pursues state of the art processes and services. Unique, superior knowledge in both precision measurement services and equipment manufacturing and reconditioning allows M-7 to provide significant value-added solutions to the metrology and manufacturing world.

As an international leader in dimensional inspection, M-7 combines portable CMM (Coordinate Measuring Machine) equipment such as an articulating arm, laser tracker, and 3 dimensional laser scanner with leading international software packages. This allows M-7 to perform tasks consisting of reverse engineering, dimensional and geometrical workpiece inspection, equipment alignment, and large scale laser scanning for applications requiring facility measuring and 3D layouts.

Figure 1: M-7 portable 3D measuring equipment. Left: articulating arm Right: laser tracker

The in-house workshop focusing on equipment manufacturing and repair often utilizes advanced measuring ability to enhance manufacturing operations and final part accuracy. The combination of measuring and manufacturing allows M-7 to offer high quality turn-key products to a wide range of industries which includes: aerospace, nuclear, power generation, automotive, steel, mining, and earth moving equipment.

2. Partnerships

Strategic partnerships with various universities, departments, and international firms are critical to the development of leading technology by M-7 Technologies. Two leading academic partners are Ohio State University and Youngstown State University. A partnership with the Department of Defense is leading the way in several projects involving M-7's advanced manufacturing and measuring capabilities. M-7 has also partnered with a leading measuring firm in Israel allowing M-7 to deliver extremely accurate and efficient measuring solutions to the US manufacturing industry.

M-7 partners with Ohio State University participating in Blue Collar Computing (BCC), an initiative sponsored by the Ohio Supercomputer Center (OSC). The goal of this program is to create global competitiveness providing the area's industry access to advanced computing technologies. This program provides creative tools such as virtual modeling and simulation, which in turn creates a competitive edge by driving this technology into manufacturing capabilities. These capabilities include reducing cycle time, labor cost, and decreasing research and development time allowing new products to be launched in a timely manner. BCC is equipped to provide training, resources, and internships as well as create partnerships with engineering firms, state organizations, industry groups, and large scale global manufacturers. BCC also provides software development solutions and research aiming to integrate advanced computing into many organizations.

Youngstown State University (YSU) also works closely with M-7 Technologies. M-7 is a member of the STEM (Science, Technology, Engineering, and Mathematics) college advisory board and is a lead commercial partner in advanced software acquisition. M-7 was successfully awarded a competitive grant from YSU, this grant will be utilized to support the research and development of future technology projects (see Section 6 of this document).

Thru the Department of Defense, M-7 Technologies has been introduced to the Army Research Lab (ARL). ARL is partners with the National Institute of Standards and Technology (NIST). M-7 is an active contributing member of NIST. At NIST, the Mechanical Metrology Division of the Physical Measurement Laboratory is responsible for the standard SI units of measure. These measurements and units are delivered in the form of specifications and standards providing technology services that promote innovation and industrial competitiveness in the United States. Working with NIST, M-7 is currently involved in multisensor, non contact comprehensive component characterization known as C-3 intelligence.

M-7 has joined forces with a leading precision measurement company located in Israel. This company has awarded M-7 exclusive distributing rights to leading edge laser technology developed for aerospace applications. This technology provides extremely accurate in-process measuring solutions taking a fraction of the time compared to competitive measuring solutions.

3. Transmission Processing

M-7 Technologies engineering, measuring, and development services enables its team to become deeply involved and extremely knowledgeable in gearbox manufacturing, measuring, failure analysis, reverse engineering, and reconditioning.

Rigorous internal procedures specify and address best practices from as-received inspection and review, thru disassembly, measuring, manufacturing, assembly, final inspection, and spin testing. Detailed attention is given to critical components such as the housing, pinion shafts, gears, bearings, and seals. Examples of a reverse engineering project of a planetary gearbox can be found in Attachment A.

M-7 utilizes advanced measuring capabilities and manufacturing to develop core competence in premature gearbox failure. The articulating arm CMM and laser tracker allow M-7 to detect the slightest manufacturing flaws during failure analysis and incoming inspections of as-received gearboxes. M-7 has concluded that gearbox bores, or bearing housings, are extremely critical to the overall functionality and operating life of a gearbox. These bores are routinely inspected to determine misalignment conditions and bore cylindricity.

An example of an inspection report performed on an incoming gearbox can be viewed in Attachment B. This inspection report compares bearing housing centerlines as-received and also reports cylindricity of each bearing housing. Based on the bearing housing alignment, or misalignment results, M-7 creates a unique manufacturing plan specific to each job. Figure 2 below states the effect bore misalignment can have on the overall life or run time of a gearbox.

Misalignment		**Relative Life %**	
milliradians	degrees	Single Row Tapered Roller Bearings	Double Row Tapered Roller Bearings
0.0	0.0000	100	100
0.1	0.0057	100	75
0.2	0.0115	100	50
0.3	0.0172	100	30
1.0	0.0573	92	-
1.5	0.0859	75	-
1.8	0.1031	50	-
2.0	0.1146	40	-
3.0	0.1719	20	-
4.0	0.2292	10	-

Figure 2: Data from industry leading bearing manufacturer showing the dependency bearing misalignment has on premature failures and shortened operating life.

When performing gearbox reconditioning workscopes, M-7 is able to detect bore misalignment and out of specification bore cylindricity. Once detected, these features can be improved thru precision machining and additional inspection.

4. M-7 Technologies Transmission Results

As a result driven company, M-7 focuses on meeting and exceeding customer expectations. Exceptional service is achieved by providing a high level of quality, technical expertise, and experience. The M-7 process contributes to customer profit by eliminating costly downtime. Particular attention is given to gearbox reliability where extended lifecycles are critical to performance.

Determining common manufacturing flaws and failure points and improving them thru precise manufacturing has proven to increase gearbox lifecycle in many applications.
Geometrical features of bearing bores are significantly improved through a series of machining and inspection operations. Similar techniques are also utilized in the manufacturing plan and measuring analysis of many other products manufactured serviced by M-7 Technologies.

A gearbox reconditioned by M-7 consistently experiences increased operating life when compared to previous life results without the involvement of M-7.

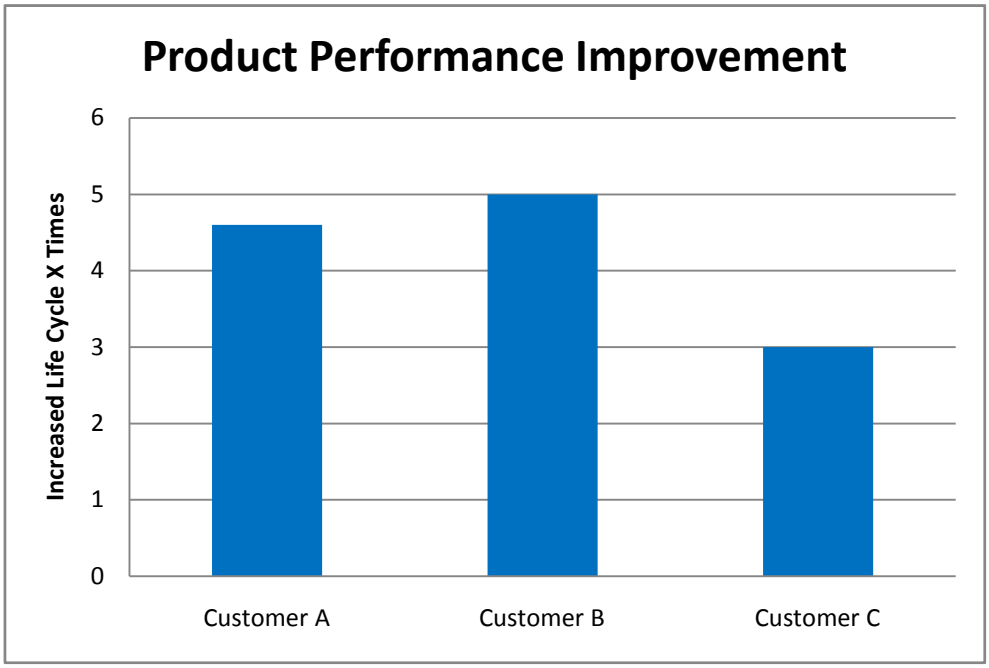


Figure 3: Customer testimonials of increased operating life of M-7 manufactured product

5. Turbine Blade Technology

M-7 Technologies paved the way for 3 dimensional turbine blade measurement. The first turbine blade mold to be utilized for US blade production was measured by M-7 using laser tracker equipment. The initial project took place in 2006 in Pennsylvania with the state Governor serving as a witness to the achievement.

The female blade molds were of significant size made of two halves each having a base to spar length of 45m with the base diameter being 2m and the spar tip being the size of a center punch.

The goal of the measuring project was to verify that the mold manufacturing process produced desired results, which in turn would produce conforming blades. A conforming blade has the correct geometrical features yielding the desired aerodynamics and blade pitch. Upon establishing proper measuring planes laser measurements were performed around the peripheral arc of each mold half. These measurements were taken every meter in length down the mold body. Each scan collects data every 3-5mm of the scanning arc measurement. This produces between 600-800 measured points around the largest diameter of the mold.

Figure 4: Photo showing the M-7 laser tracker preparing to measure a wind turbine blade mold

Because the inspection was conducted on two halves and naturally the mold's proper function is one piece, both measured halves had to be meshed into the same coordinate system. Leading software along with technical knowledge of the product and measurement process allows for a virtual model of the actual mold to be created. This model is then compared against desired results and specification. Since the initial project M-7 has received additional follow up orders to inspect new molds as warranted by production needs and mold wear.

Similar to the blade mold project, M-7 is also involved in the actual measurement of turbine blades. These measurements can be performed with both the laser tracker and laser scanning equipment.

The 3D measuring will search for and detect surface, geometrical, and material flaws through detailed scanning of all blade surfaces.

M-7 is also experienced in measuring and analyzing the hub of a wind turbine. This hub is also known as the rotor once it is coupled to the blades. These hubs are measured 3 dimensionally when in the form of a rough casting ensuring early stage workpiece accuracy. The goal of the project is to conduct a dimensional inspection comparing numerous values on a 2 dimensional drawing to that of the 3 dimensional workpiece.

6. Technological Plan for the Future

M-7 Technologies constantly pursues new technology in order to achieve ideal component perfection. This is through in-house research as well as strategic partnerships. M-7 currently holds a seat on the International Standards Development Committee while participating in several international symposiums and sitting on numerous advisory boards.

M-7 would entertain discussions with customers to integrate the gearbox manufacturing process with condition monitoring software. Performance of the gearboxes could then be monitored in the field allowing the M-7 performance improvement process to be validated while giving rise to predictive and preventive plans.

One example of a technological partnership is one with INORA (**In**telligent **O**ptimization **S**elf **R**egulated **A**djustment) who provides a very advanced geometric math engine. INORA is part of an Advanced Technology Research team that is developing the configuration of a device to be mounted in the spindle of CNC machines for in-process measurement of parts as cut. This will provide high speed, high precision, high accuracy, in-situation non-contact measuring for quality assurance and quality control checks on high value, mission critical part manufacturing processes. The dimensional and geometric data collected will be driven directly into the native design file and have the ability for intelligent machine adjustments. In the future, instantaneous information transmission will enable real time collaboration in a distributed manufacturing environment.

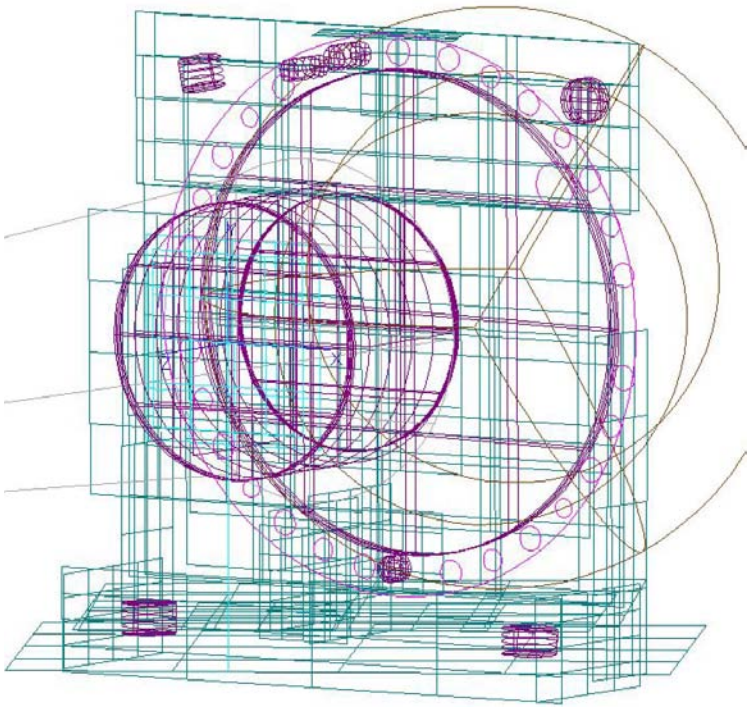
To further expand on this technology and for overall product enhancement, M-7 is currently developing material characterization instrumentation that will combine ultrasonic inspection, eddy current, and X-ray diffraction capabilities with other baseline measurement data. This equipment will allow for design parameters to be compared to real life workpiece characteristics. These design parameters can also be analyzed, tested, and determined through use of this software. Finite Element Analysis and simulations can then be performed to determine life span of a product prior to the product ever reaching the OEM or the field.

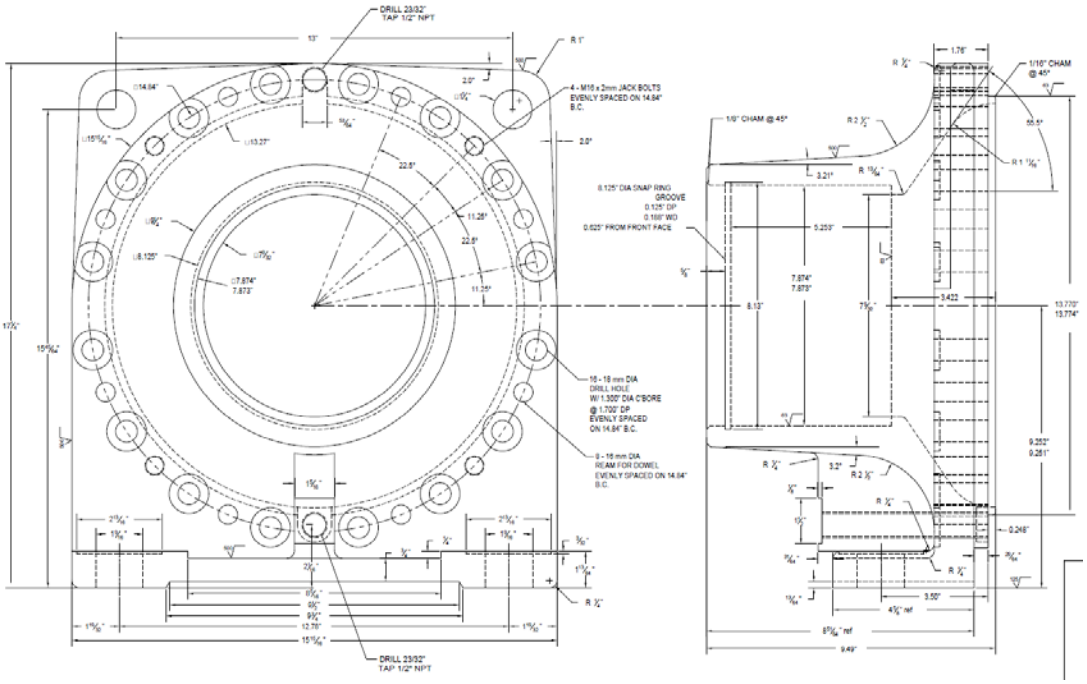
This equipment has the opportunity to revolutionize the wind industry by significantly enhancing design and manufacturing capability. It has potential applications for transmission (gearing) as well as blades.

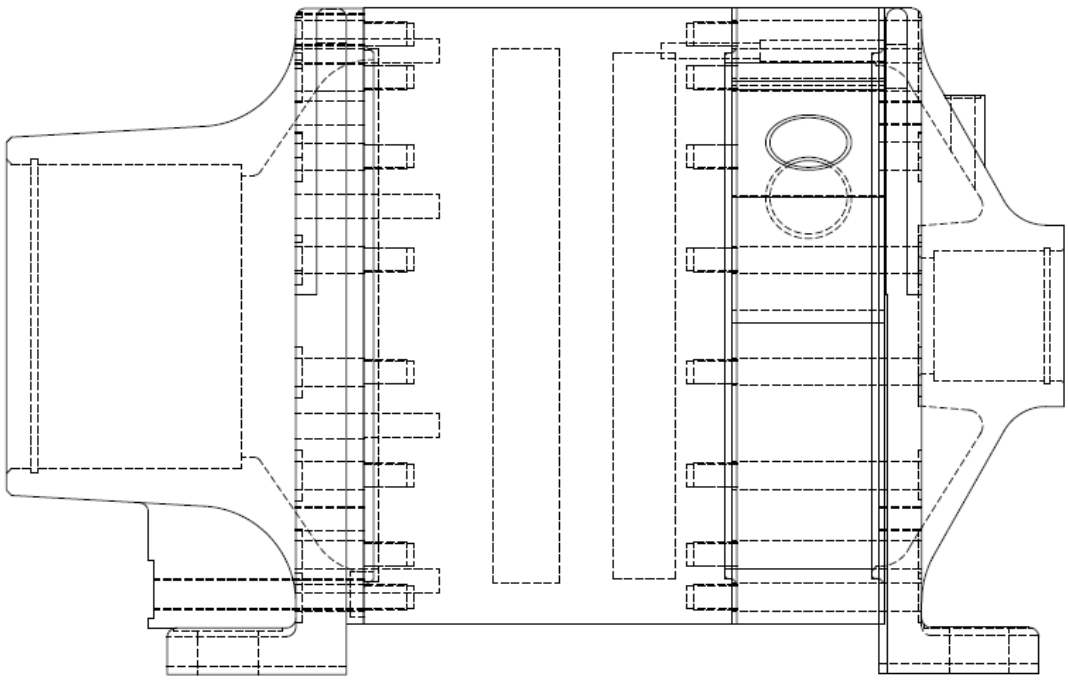
7. Summary

To achieve solutions that meet and exceed customer expectations M-7 Technologies combines advanced measurement and manufacturing with technical skill set and problem solving ability. Product optimization and improved performance are examples of outcomes using the procedures and capabilities of M-7. It is the belief of M-7 that there are significant opportunities for process and product enhancement in the wind turbine industry. M-7 invites future collaboration to identify and solve continuous improvement opportunities and projects.

ATTACHMENT A – Planetary gearbox reverse engineering project – wireframe, component drawing, and assembly view

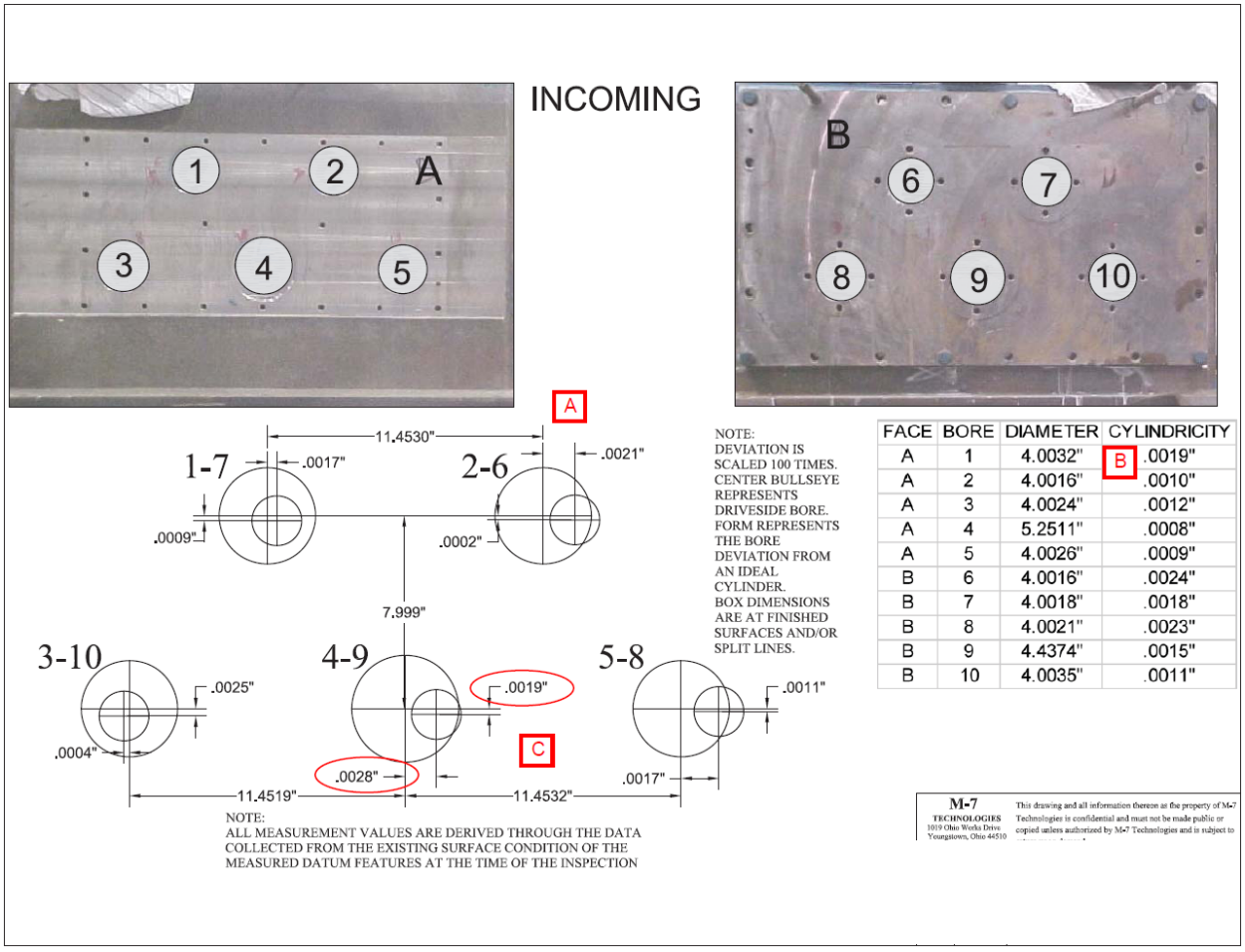






ASSEMBLED AT 0.75 SCALE

ATTACHMENT B – Incoming Inspection of Gearbox



FACE	BORE	DIAMETER	CYLINDRICITY
A	1	4.0032"	B .0019"
A	2	4.0016"	.0010"
A	3	4.0024"	.0012"
A	4	5.2511"	.0008"
A	5	4.0026"	.0009"
B	6	4.0016"	.0024"
B	7	4.0018"	.0018"
B	8	4.0021"	.0023"
B	9	4.4374"	.0015"
B	10	4.0035"	.0011"

A – Dimensional analysis comparing alignment of related bearing housings

B – Overall cyclindricity measurements of each bearing housing, or bore

C – Misalignment values between related bearing housings