A TECHNICAL WHITE PAPER FOR INDUSTRY

TESTING AND EVALUATION of MARK 9 (50-100 HP CHASSIS) INFINITELY VARIABLE TRANSMISSION

Conducted in Association with Southwest Research Institute (SwRI)

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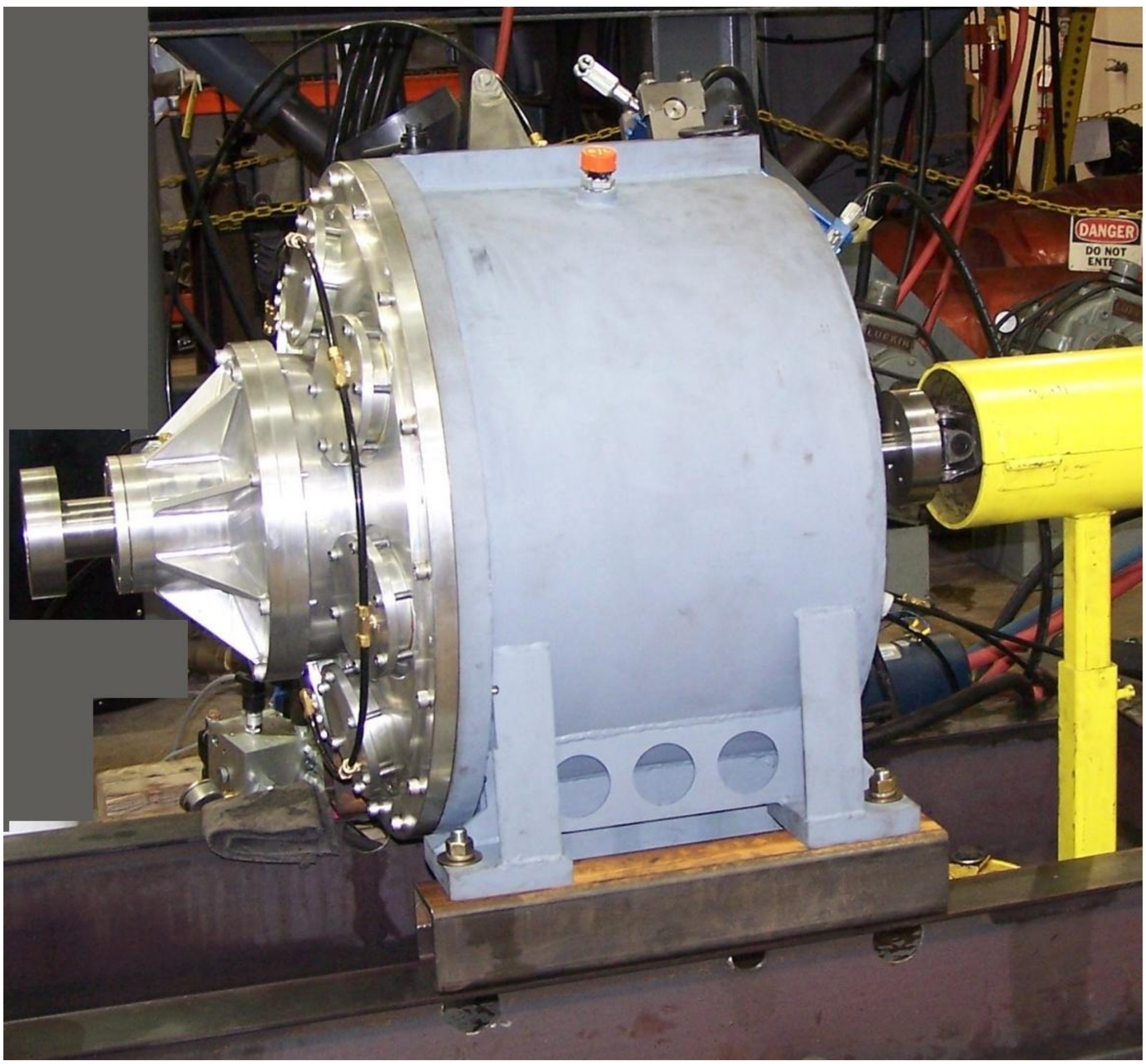


INFINITELY VARIABLE TRANSMISSION – Mark 9 (50-100 HP CHASSIS)

Executive Summary

Turbo Trac designed and developed an Infinitely Variable Transmission (IVT) for use in various industrial applications. This IVT has been designed to address performance standards developed in association with a strategic partner in the oil/gas market. Therefore, some of the standards may not be applicable to all industrial applications. Turbo Trac USA, Inc. developed a protocol to establish mutually acceptable testing procedures and milestones. The protocol includes procedures, information and instructions required to test and record the results.

Turbo Trac's IVT is designed to provide torque and speed variation in an industrial system powered by electric motors, internal combustion engines, or various other prime movers. It functions similar to a variable speed (or frequency) drive (VSD or VFD) used with electric motors. A key characteristic is the IVT's ability to reduce energy consumption while increasing system reliability in most applications.

The IVT tested is rated at 100 HP. It is one of a family of three output ratings based on the same chassis. The three ratings are 50 horsepower, 75 horsepower and 100 horsepower. These variants are achieved by varying the internal traction devices. The unit shown in the cover photograph is specifically adapted for belt drive input and output. The IVT can also be configured for directly coupled input and/output installations.

All testing was done at Southwest Research Institute (SwRI) of San Antonio, Texas and the data was provided by SwRI.

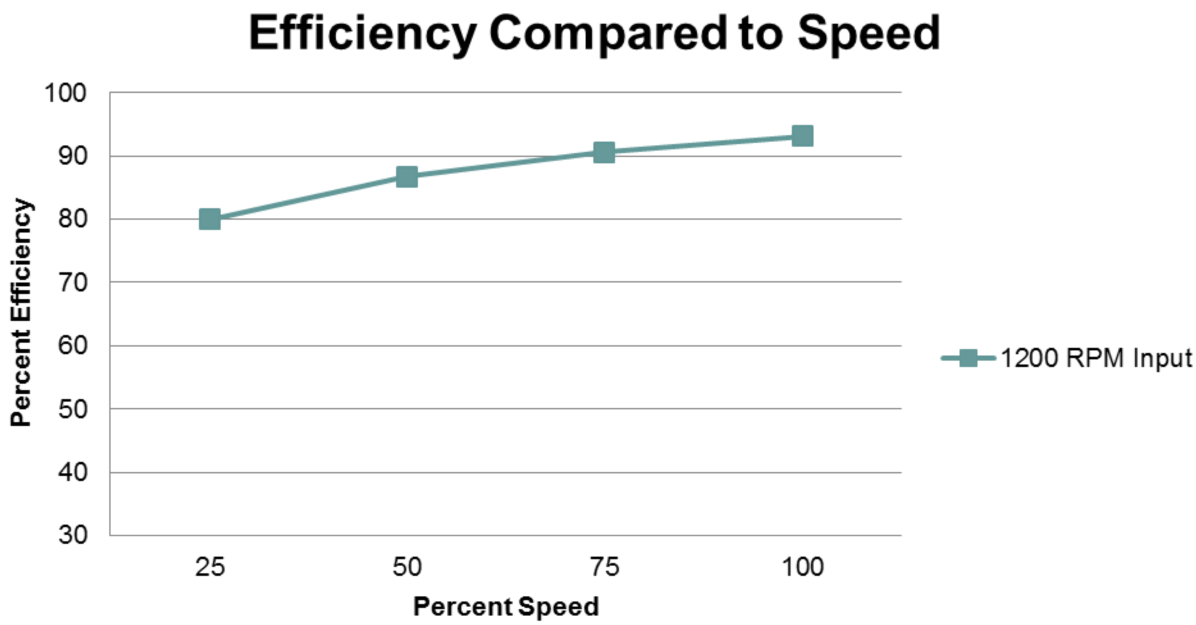


Figure #1 – Mark 9 Testing Efficiency

The IVT was tested at 50, 75, and 100 HP input at 1200 rpm input speed and at various output speeds. No slip within the traction components was experienced. SwRI could not test beyond 100 HP with the test configuration. Efficiency ranged from 80% at 25% of rated output speed to 93.1% at maximum output speed. Rotational losses, vibration, and noise levels were also documented.

In conclusion, The Mark 9 design demonstrates that the improvements in efficiency allow the IVT to be superior to VSDs in most applications. The unit operates within the allowable temperature range without external cooling features. Vibration was well within design requirements. Noise attenuation will be application specific and can be addressed with continued improvements and engineering controls.

Introduction

The first industrial prototype (Mark 8) was developed for belt driven, oil-well pumping systems. The Mark 8 unit was fabricated and assembled in late 2009 and then subjected to extensive testing procedures during the period of January through June of 2010. Testing was performed to a) determine the physical and performance strengths and weaknesses, b) overall performance characteristics; and c) any modifications needed to further improve performance and lead to a production design.

In June, 2010, work began on the design and subsequent fabrication of the Mark 9 unit that incorporated the design improvements identified in the Mark 8 unit assembly and testing process as well as customer feedback sessions during 2010. The Mark 9 unit was assembled in November 2010. Testing was completed in December at Southwest Research Institute (SwRI) in San Antonio, Texas. The results and analysis of that testing is outlined in the body of this report. All detailed test data are available from Turbo Trac USA, Inc.

Background

The primary purpose of the Mark 9 prototype effort is to optimize the unit efficiency to meet the performance requirements for a 50 horsepower transmission unit with 1.5 peak overload. As noted earlier, this is the first model in a family of transmissions built on a common chassis using common components. The Mark 9 is the common chassis and the common internal components to be used in this chassis.

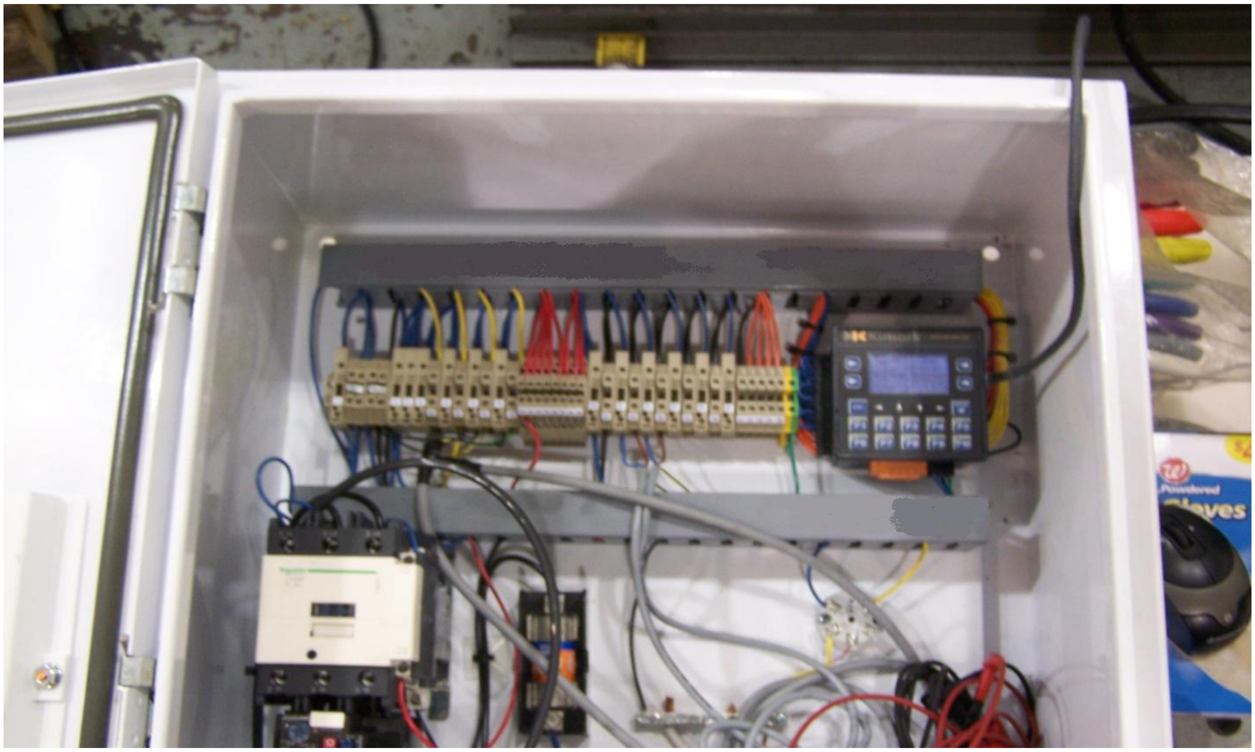
The lessons learned from Mark 8 design/assembly/testing as well as the recommendations contained in all the Mark 8 testing reports was compiled into a design review process for the development of the Mark 9 design. The prioritized foci of the design review were to; a) improve operational efficiency, b) simplify design to reduce manufacturing cost, c) reduce fluid heating to allow for operation without external cooling (reducing cost and complexity), d) reduce noise. The results of the design review and customer feedback were incorporated and subsequently led to fabrication of the Mark 9 unit. The new components were assembled by Turbo Trac and delivered to SwRI for testing in December 2010.

Summary of significant design enhancements of the Mark 9 design

Design Enhancement	Customer Benefit
Reduction of machined components by 41%	Unit weighs approximately 1000 lbs. and 36 measures inches cube (100 HP model)
Reduction of off the shelf components by 20%	Reduced end user maintenance
Standardized housing and components to support family of products and interchangeability of parts	Reduced end user parts inventory cost for multiple IVT units
Option of speed control features in electronic, hydraulic or manual.	Flexible interface with existing external control systems.
Option of internal or external traction fluid pumping features	Flexible interface with existing external control systems.
Option of logic controller or integration to customer controls	Flexible interface with existing external control systems.
Option of communication from logic controller to customer controller over Modbus, Ethernet or Radio	Flexible interface with existing external control systems.
Increase in lubrication sump size	Ensure internal heat dissipation is maximized

Control Features

Further enhancement to the design included a multi-choice output control and management system. The Mark 9 control function allows selection from a mechanical, manual output speed adjuster to a fully automated, compact Programmable Logic Controller (PLC) that will monitor industrial system performance and control the transmission’s output speed. The hydraulic control contains an electrical contactor to start and stop the hydraulic pump. Field devices include two solenoids to control the position of the disc, two pressure transmitters to monitor fluid pressure, and one temperature sensor. All operator functions are controlled from a control pad on the front of the PLC. The PLC is also designed to communicate with customer over-riding controllers. Also available is a laptop based monitoring and diagnostics software program.



Control Cabinet - PLC in upper right hand corner, motor starter in bottom left corner

Testing at SwRI

Testing was completed in December 2010 at Southwest Research Institute using Turbo Trac's standardized test procedure.

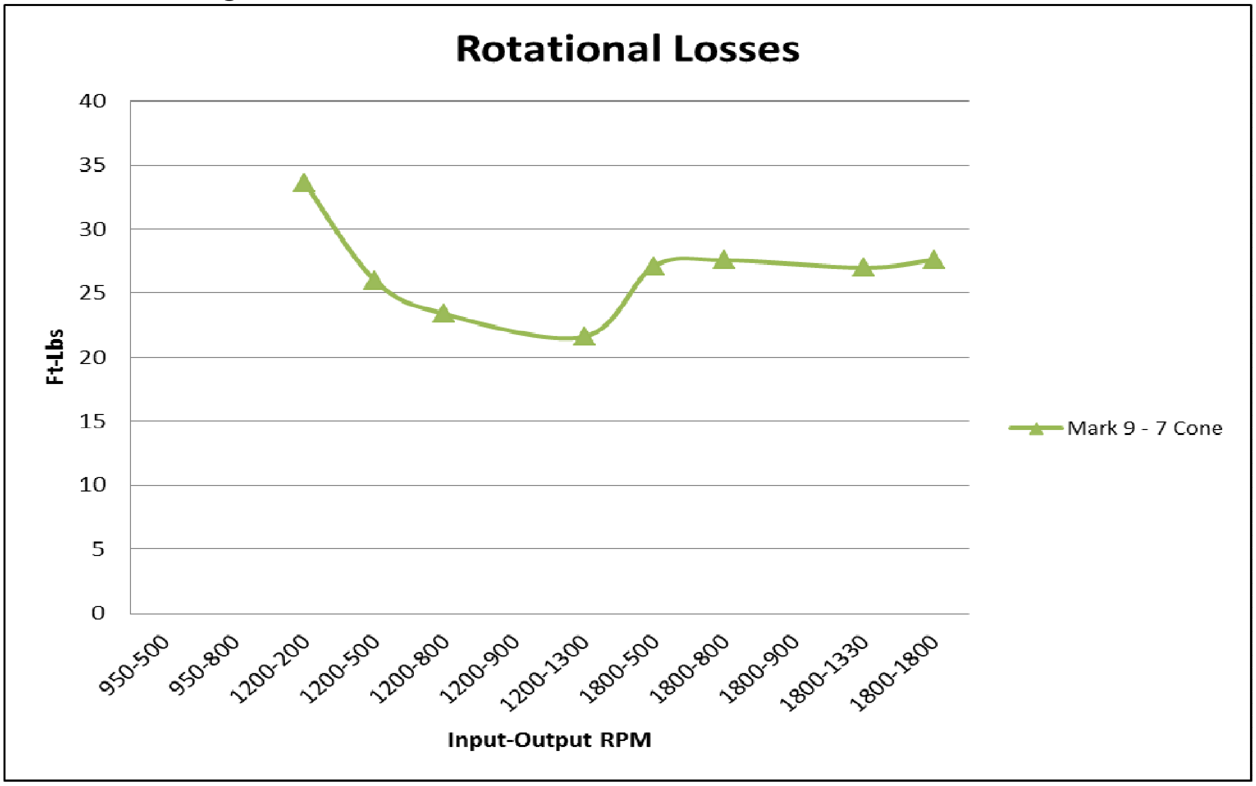
The first test procedure was conducted with the dynamometer uncoupled (no external load) to determine the horsepower required to rotate the internal components without any external load.

A second set of tests was conducted with the dynamometer engaged (an applied load) and results were measured at varying input speeds, output speeds, and loads. Throughout the testing, background and operating noise readings were taken with a digital measurement device in a stationary position throughout the full testing period.

The third set of testing was focused on performance requirements established in conjunction with industry partners.

Rotational Losses - The first test procedure was conducted with the dynamometer uncoupled to determine the horsepower required to rotate the internal components without any external load. The outcome of this testing indicates that rotational losses are relatively level for the speed range collected.

Results of Testing - Rotational Losses:



Results of Testing – Noise

Noise adjusted for background peaked at 100.97 dba. All the readings were in the 99-101 dba range. This includes loaded and unloaded conditions and change was negligible for speed. Noise is attributable to the planetary gear set and more specifically gear tooth profile. Engineering solutions are now in process to control noise in the commercial unit.

Results of Testing – Vibration

Vibration averaged .068 in/sec during testing. Peak recorded vibration 0.14 in/sec.

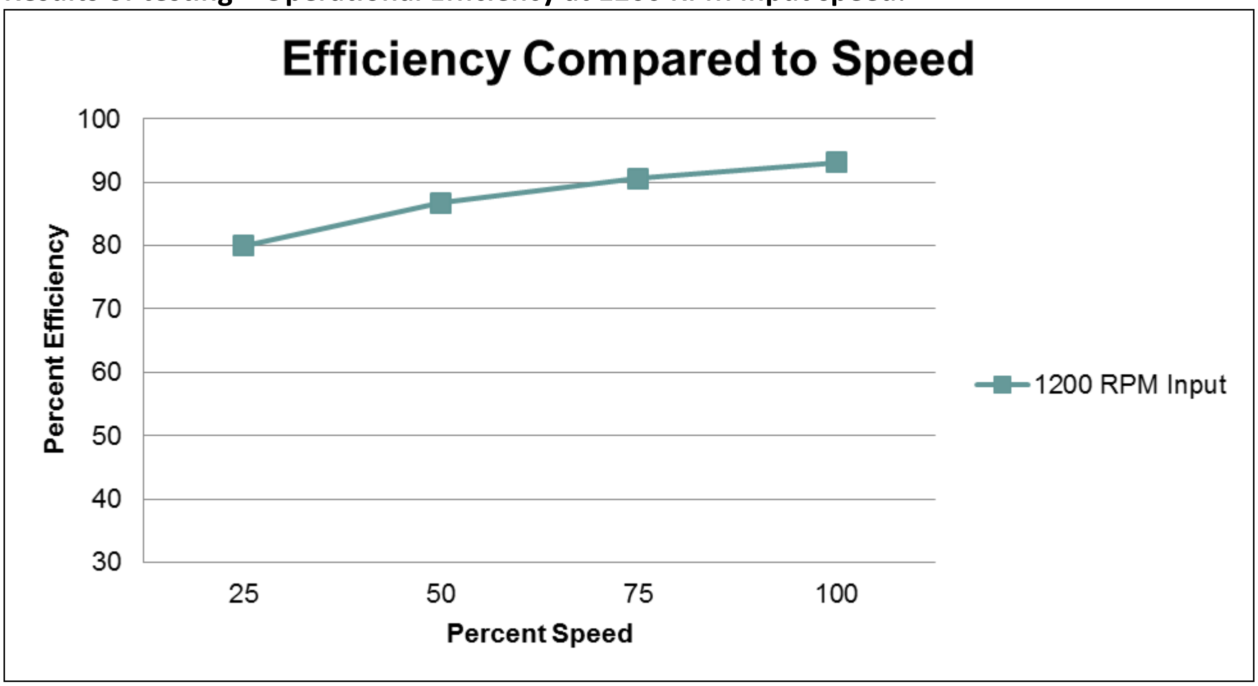
Results of Testing – Temperature

Temperature ranged from ambient to peak values of 185 degrees F (85 ^{o}C). This is well within the operating range of the traction fluid, -30 to 330°F (-34 ^{o}C to 166 ^{o}C) and well within the peak ratings of

the bearings, 225°F (107 ^{o}C). Temperature actually decreased when output speeds is increased. This is attributed to the fact that as transmission output speed increases, the planet gears on the carrier slow down.

The SwRI report stated that a "tube and shell heat exchanger was used to cool the lubricant for the Turbo Trac transmission". The heat exchanger was installed to dissipate heat but not utilized.

Results of testing – Operational Efficiency at 1200 RPM input speed:



The graph above represents the efficiency of the IVT at 1200 RPM input speed, 100 HP output load, and varying output speed. Changes to input speed and output load will also have varying impact on overall efficiency.

Conclusions

After extensive testing under a 100 HP load, the transmission was opened and inspected to determine the condition of the cones and disc.

Although the IVT had under-gone significant cycling of the disc along the full length of its travel under high loads, the disc and cone surfaces had no indication of wear or stress.

Three cones from Mark 9 unit after testing

The hydraulic actuator has proven to be a simple, cost effective solution for applications that do not require fast response times and high resolution. As an upgrade the electronic solution will meet all response rate and resolution needs.

The external traction fluid pumping system was very effective. A review shows further opportunity to optimize the pumping system and these steps are already underway.

The current design meets the power throughput and efficiency demands of the market. With the improvements gained in the reduction of rotational and the data collected during the testing of an 8, 7, and 6 cone configuration, the manufacturing unit configuration can now be defined. The 7 cone configuration on the standard chassis will carry 100 HP in continuous operation, 75 HP design will have 6 cones and 50 HP will be supplied with 5. This is based upon a 1.0 service factor.