TECHNICAL DESCRIPTION
(LVDT GAUGE)

McNAB SHAFT HORSEPOWER

MONITORING SYSTEM

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Technical Description of the McNab Shaft Horsepower Monitoring System

Statement of Goals

The technical problem to meet or exceed the ship's specifications or equal.

The key points are as follows:

A. There must be mechanical proof of span calibration

B. The monitoring system should not have a high powered HF transmitter constantly radiating an unwanted homing signal.

As to A, the typical torque system brought to market had difficulty proving to the naval architect and mechanical engineer that span sensitivity was correct at, during, and after sea trail. Early on, a mechanical gage measurement was chosen verified the span accuracy and the sensor was moved "the agreed upon torque amount" resulting in the correct instrument span. Span proof was to be done just hours before the start of sea trial and hours afterwards (this avoided the argument that something might have slipped during trials) or alternatively a portable stand useful for calibration. See Appendixes 3 & 4.

As to B, this will be explained and addressed in detail in later paragraphs. But the short of it is the SHP meter should not unintentionally introduce a significant radiation source to the ships electromagnetic profile.

Introduction

The McNab Shaft Horsepower Monitoring System has been designed for permanent and sea trial shipboard use in measuring shaft torque, shaft RPM, and automatically computing shaft horsepower. The system is comprised of a shaft mounted rotary transformer (patented) to apply operating power (for shaft mounted electronics), a shaft mounted assembly to sense torque on the shaft, a shaft mounted transmitter to transfer a signal proportional to the sensed torque off the shaft, to a hull mounted receiver, a digital shaft RPM sensing system, and a digitally metered indicator panel displaying a variable choice of torque, RPM, and SHP readings and providing a separate auxiliary 4-20 mA current output for all three measurements.

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Shaft horsepower is the amount of power developed on the propulsion shaft of a ship in order to propel the ship through the water. Shaft horsepower is the product of the shaft torque and the speed at which the shaft is revolving, times a constant. Torque signal is the degree to which the propulsion shaft is twisted while performing work (1).

The McNab Shaft Horsepower Monitoring System determines shaft horsepower by accurately measuring shaft torque and shaft RPM and then automatically performing the mathematical computation necessary to arrive at the amount of horsepower developed on the shaft. Accuracy is independent of the shaft speed, direction of hull motion, shaft mounting location, or vibration.

Technical Description

The McNab Shaft Horsepower Monitoring System is comprised of the following (see drawing, Appendix 1).

> A rotary transformer that applies 50 or 60 Hz ships power onto the shaft for the shaft mounted electronics (consisting of signal conditioner power, primary and secondary.)
>
> To measure torque, a strain sensor gage is mounted on its frame that is mounted on to the shaft.
>
> A shaft mounted transmitter (XMTR) that transmits a low powered FM signal proportional to the amount of torque determined by the torque sensor.
>
> A protective cover (husk) that shields the shaft mounted components against EMI/RFI interference, capacitively couples the torque signal off the shaft, and protects the components against physical damage.
>
> A hull mounted receiver (signal conditioner torque) that receives and decodes the torque transmitter signal.
>
> An RPM sensor and electronics to determine shaft RPM by sensing Husk RPM holes.
>
> A digital indicator panel to display a user selective choice of TORQUE, RPM, or SHAFT HORSEPOWER, and provide (typically a 4-20 mA current) signal outputs proportional to the three parameters.

Rotary Transformer

The system utilizes a patented Data Couple Transformer (2) to get the electrical power necessary to space the shaft-mounted transmitter. This means of providing power to the shaft eliminates the need for slip rings/brushes and provides AC power at a ships normal 50/60 Hz 117 VAC as opposed to other methods of applying electrical power on the shaft, which otherwise would typically apply a high powered frequency (RF) transmitter - 100 watts to accomplish the task. This RF transmitted could be a possible source for shipboard interference, remote signal detection (EMI) or homing signal radiating down the shaft to the outside.

Gage Construction

The strain gage frame construction is as follows:

A light metal frame of approximately 16 inches in length and 3 inches wide is clamped to the shaft. It is clamped to the shaft outer diameter (OD) at either end at its four points. Extending in from either end of this frame are two metal arms. At the junctions of the two arms is the sensor device consisting of a magnetic transformer and its metal core. The relative position of the core to its transformer is the sensor detection method. The sensor device is used to measure the OD mechanical movement caused by the "give" of the steel shaft upon application of torque transmitted via the arms and metal frame.

Steel of a certain type will give upon the application of torque predictably according to known formula based upon the elasticity of the steel shaft. The more the force (torque) applied, the more the transformer movement. The sensor measures this shaft OD mechanical change and its motion absolutely faithfully transmitted to the torque sensor there will be a 1:1 relationship.

Further it is ultra-important that the torque sensor relationship faithfully follow that of the shaft OD movement - ideally 1:1. But, where a stiff sensor bar resists the torque displacement, the sensor mounting ring clamps flex, and this small flexing will cause the gage to see less torque than actual. Thus, the torque will be under-read. This error (½ to 1%) cannot be detected (or calibrated out due to its being shaft size dependent) or by just stressing the bar out of its mounting rings. This unwanted flexing factor is called "attaching compliance factor." But with its highly flexible frame (the operating force is 8 oz.), the McNab sensor has the ability to track to 1:0.997 and is independent of the shaft size so that it may be factored out by an engineering constant.

The McNab sensor is constructed of sealed magnetic transformer whose balance is changed by its core location. The core is fixed to one end of the frame and the transformer is attached to the other end of the frame. In this way shaft's elasticity twisting is resolved across 16 inches and following the shaft's outer diameter. By the frame (and its coupling to the shaft), this core movement causes the transformer balance to change and resulting current is picked up by the transmitter preamp. In turn, it is processed at the shaft mounted transmitter as a variable AC signal directly and linearly proportional to the full shaft torque movement. (this typical displacement ranges from 0.010 to 0.025 inches at full scale). The anticipated life of the coil has been proven out to be greater than 20 years.

No shaft modifications are required for assembly mounting.

Transmitter

The transmitter: 1) Provides an AC excitation frequency to the coil sensor,
2) Receives an output signal from the sensor that is proportional to the torque on the shaft, and 3) Conditions the signal to be coupled through capacitance to the hull mounted receiver. Capacitance signal transfer keeps the signal transmission level down to less than 10 milliwatts, to avoid unwanted radiation.

The transmitter supplies a 1560 Hz signal to the coil sensors. As torque induced strain is developed on the shaft, this frequency changes. This core alters the 1560 Hz excitation frequency an amount proportional to the sensed strain, producing a torque AC signal proportional to the period of the signal. This 1560 Hz sub carrier is FM modulated at 10.7 MHz. This RF signal is attached to the Husk cover. Transmitter electronics provide electrical isolation for protection against variable power loading and transmitter output loading. This signal is always an AC signal avoiding solid state DC drifts resulting in a measured drift of less than 0.1% per year.

The torque signal is brought off the shaft husk to the stationary hull side receiver via FM telemetry at a carrier of 10.7 MHz using the method of capacitance coupling and it is received at a closely located metallic foil attached to the signal conditioner receiver input.

Shaft Husk

The protective cover prevents EMI/RFI emissions from affecting the shaft mounted components, serves in the capacitance coupling of the signal from the shaft to the hull mounted receiver, and protects the shaft mounted components against physical damage. Better than 20 dB of shielding between EMI/RFI radiation and the shaft-mounted components is provided by the cover.

Shaft Cover

Depending on location, the shipyard may install a protective removable grating to protect crew and equipment in consideration of the rotating shaft. This needs to be easily removable for service. Such a cover is recommended.

Receiver

The torque signal conditioner accepts and decodes the torque signal transmitted and provides a DC voltage/current output proportional to the sensed torque for input to the SHP panel or other requirements.

After FM signal reception, the modulated signal is sent through an LC bandpass filter and then a ceramic bandpass filter to clean unwanted RF frequencies from the signal. The signal is next demodulated and further filtered by a Phase Locked Loop circuit. The demodulated signal is at the same low frequency (sub carrier) as the signal before the 10.7 MHz modulation performed by the shaft installed transmitter.

A second Phase Locked Loop circuit, configured as a tracking filter, creates a synthetic signal at the frequency identical to the subcarrier signal; but this new synthetic signal is free of interference noise. (This PLL principle is used on space flights, where by necessity, low level transmissions must be decoded accurately and consistently. In fact the signal is no longer the actual signal but one just like it.)

This filtered torque subcarrier signal is then sent to a decoder integrator circuit, which also produces a dc output signal. Integration smooths AC interference and the current output reduces possible ground loop problems and further providing good resolution and the possibility of longer cable runs to the indicator panel without signal degradation. The interconnecting cable is to be shielded and good engineering practice routes such cable away from high powered electrical current.

Signal to Noise Ratio

Signal to noise ratio reflects a receiver's ability to differentiate between the desired signal and the unwanted interference caused by EMI/RFI noise in the environment (i.e., fluorescent lighting, motors, SCR, generators, and communication equipment all produce noise). The receiver circuitry described in the previous paragraph provides a high modulation index: 150,000:10 million verses 1500:10 million typical in many receiving systems, resulting in a signal to noise ratio of at least 40 dB (noise levels must be 10,000 times greater than the torque signal to affect reception).

RPM Sensing Equipment

The RPM sensing portion of the system is comprised of a hull mounted proximity detector that counts evenly spaced holes around the circumference of the cover (husk) mentioned in the "Protective Cover" section. The proximity detector signals each time a hole in the cover passes the detector. Electronics are programmed according to the number of holes in the cover and a function relating the number of holes to the speed at which the shaft is revolving to determine shaft RPM and provide a dc output voltage proportional to that RPM. Self-calibration is achieved by using the shipboard 60 Hz as a reference frequency

Accuracy of 0.1%, (even down to jacking speed), is achieved because rather than sensing RPM on a one or two holes per revolution basis, our method samples shaft RPM between 16 to 28 times each time the shaft revolves for greater resolution.

Indicator Panel

The torque and RPM outputs from the receiver unit are sent through shielded ship cabling to an indicator panel. The panel electronically multiplies the two input signals according to the function required to derive shaft horsepower from torque and RPM. A selector knob allows shaft horsepower, torque, or RPM to be displayed on a 3½ numeric, red LED, digital meter. Isolated 4-20 mA auxiliary current outputs, proportional to shaft horsepower, torque, and RPM are available from a terminal block located within the panel.

Calibration

The system is shipped with torque span pre-calibrated by employing the classic mechanical formula. The McNab engineers record their result onto the Certification Data Sheet (CDS) associated to the job and mounted into the ships manual. This calculation is recorded as a movement (distance “d”) between the sensor coil and core expressed in inches at full power. The gage sensor frame is set up here in the factory in a calibration fixture. Taking the “d” data from the ship’s CDS, our technicians temporally swing the coil that “d” amount called for by the CDS and read on the digital dial gage (resolution of 0.0005 inches) and then adjust SPAN control such that the output matches the torque value that has been called for in the CDS calculations (see dwg 62281 or 52166 - appendix). With a fixture and signal condition torque electronics, the span calibration may be repeated at other locations. For that matter the span verification may be done after the unit has been installed on the ships shaft at pier side.

No further span calibration is required (but may be done) even after the system has been zeroed at the shaft as the two controls are independent. Shipboard Zero calibration of the system follows the guidelines laid down in the SNAME Code for Sea Trials, 1973 (5). Span calibration, (or more accurately stated verification, where required) is performed according to universally accepted methods (6, 7, 8). An additional sea trial torque meter is not technically required (but by practice or contract employed) but may be employed.

An exclusive feature is the ability of the shipyard technicians to perform the coil movement (d) at the ship pier side (see dwg 62281- appendix) under view of your mechanical engineer to witness first hand the correct span accuracy. This is a superior advantage resulting in money and other savings as being not as complex that having to dismount, handle, ship to a remote location, set up, test, evaluate results and reverse above etc. remount the sensor in order to prove the calibration. This makes the ship independent of shore side or foreign off shore calibration (See issue A above). This on shaft calibration represents increased capabilities over what is typically supplied.

Construction - Survivability

The McNab system meets the military specification requirements for shock and vibration, (ours is shock Grade A where as we believed Grade B is typical for Navy SHP meter, vibration to 40 Hz as opposed to something less, weight at 120 pounds as opposed to 625 lbs and EMI at 10 volts per meter as opposed to typical 1 volt) as well as excellent accuracy and stability, environmental, airborne and structure-borne noise, and EMI/RFI interference. The sensors and all electronic components are hermetically sealed for protection against shaft alley wash downs. The equipment fits into less space than the systems presently installed.

Reliability - Repeatability

Through the use both shipboard AC power and signal telemetry between the shaft and hull mounted components, thus reducing maintenance requirements. Exciting the torque sensor core with an ac signal and the subsequent ac coupled signal conditioning eliminates drift problems inherent to typical marine torque meter dc excitation and signal conditioning, providing unparalleled long-term stability. We have had life testing of the SHP system over 10 years with any failure (see photo attached A08-80 Torque Meter Life testing station) .

Spare Parts/Service

All spares for our products are available off-the-shelf. We offer worldwide service, as well as internet and toll free support.

Interconnection cabling

Interconnection signal cabling needs to be considered. The cable routings along side noise making SCR generator at 400 amps would be imprudent even with the best of double shielding - the cabling should be in instrument trays remote from noise. Good shielding cabling suppressing the exterior noise by 30 db is suggested. Circuit outputs of low impedances are used in the 4-20 signal outputs.

References

(1) Standard Handbook for Mechanical Engineers, 7th Edition, McGraw Hill, New York, 1967

(2) McNab CDS Form 61100-D

(3) James W. Dally and William F. Riley, Experimental Stress Analysis, McGraw Hill, New York, 1978

(4) Simon Haykin, Communication Systems, John Wiley & Sons, New York, 1978

(5) Technical & Research Code: Code For Sea Trials 1973, The Society for Naval Architects and Marine and Engineers, New York, 1974

(6) See reference 3

(7) The Shaft Horsepower Handbook, Book #A88-28A, McNab Inc., New York, 1988

(8) Reference Data for Experimental Stress Analysis, Measurements Group, Raleigh, 1979

(9) Military Specification: Torsionmeter (For Measurement of Torque Deflection of Propeller Propulsion Shafts of Naval Ships), MIL-T-24448A, 20 April 1971

(10) Suggested Shipboard Quality Assurance Form A79-39

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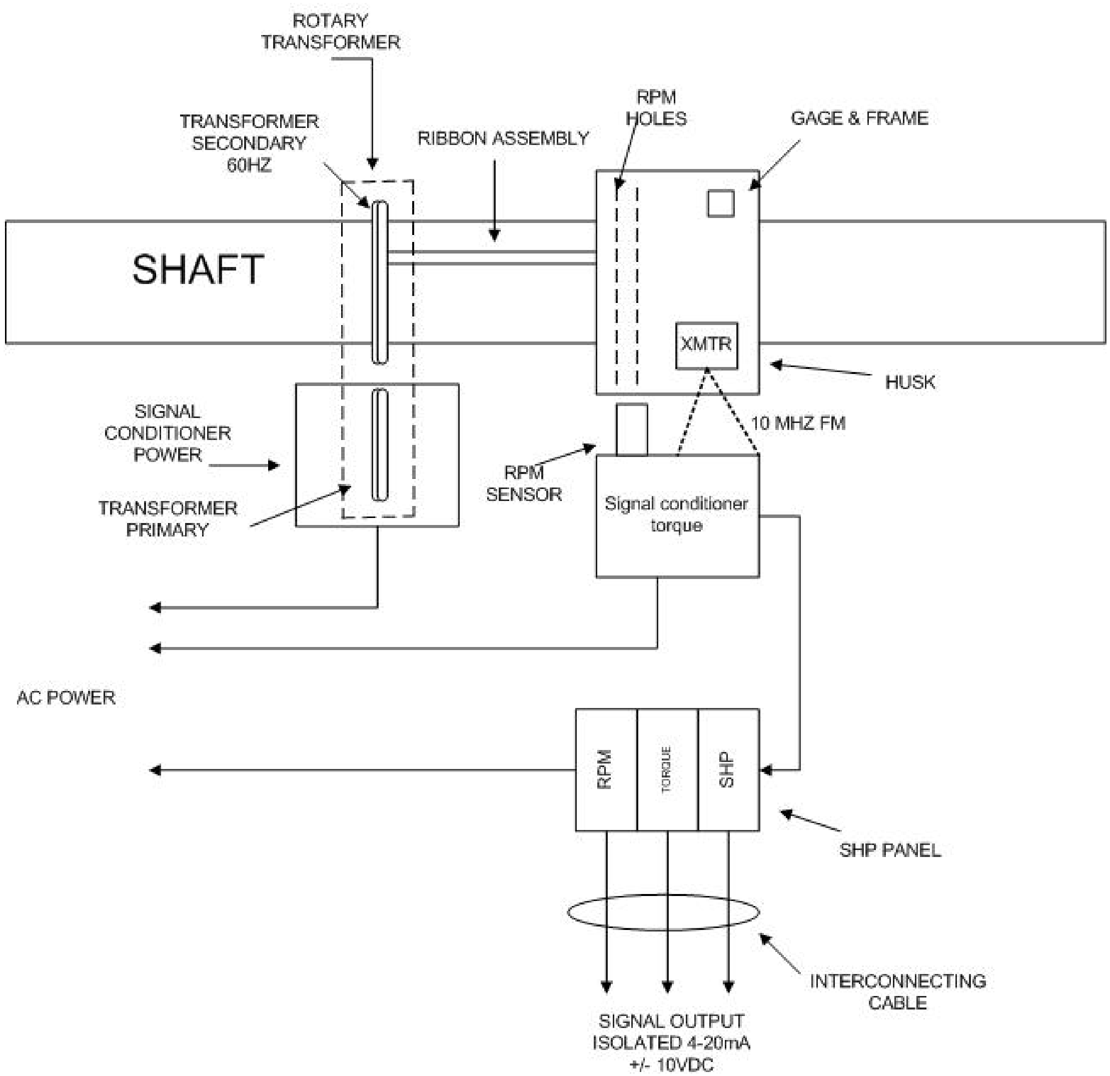
Appendixes

The following appendixes are provided:

APPENDIX 1, Relationship of Units



RELATIONSHIP OF UNITS

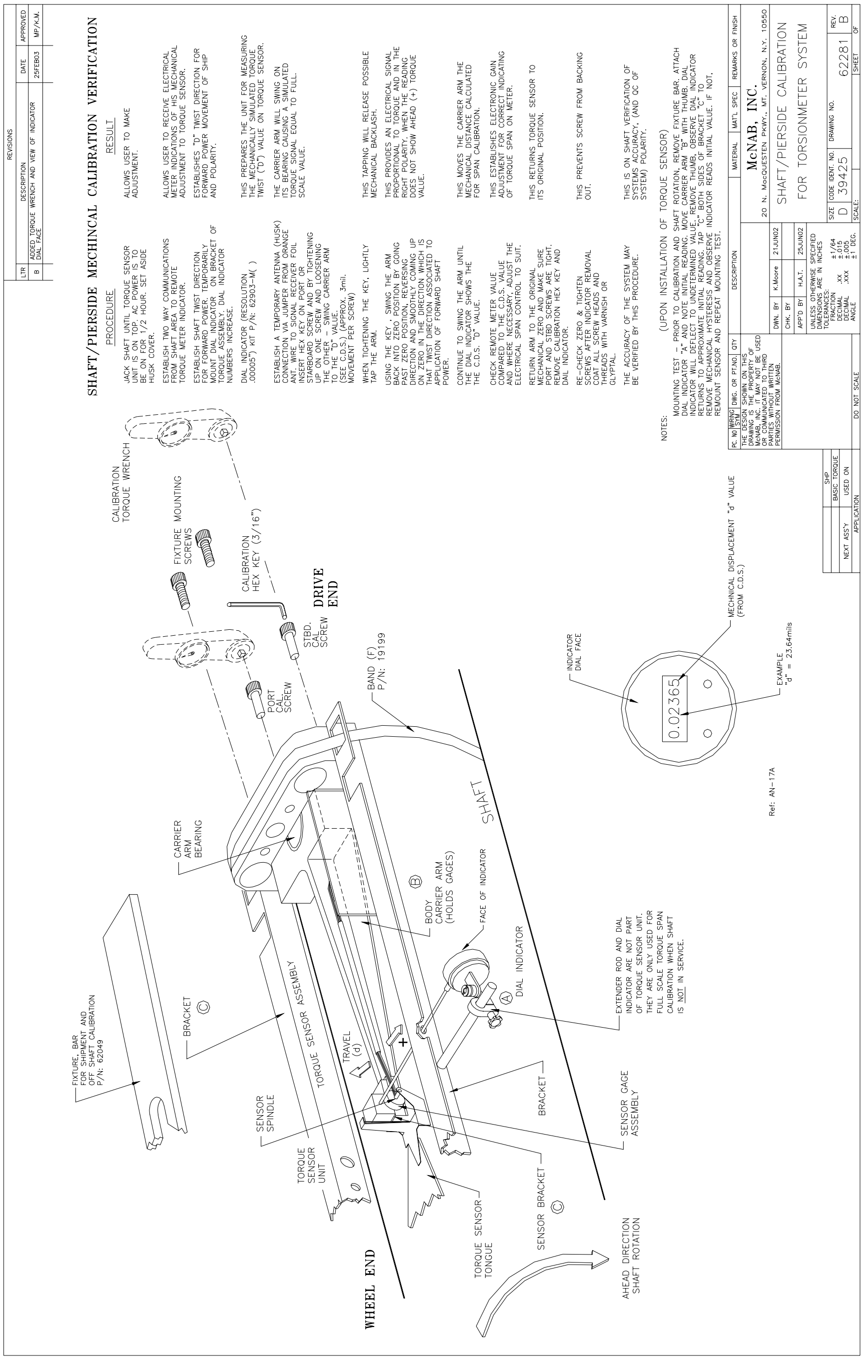
APPENDIX 2, Technical Specifications

PRODUCT SPECIFICATION – McNAB TYPE MODEL SERIES S10702	
System	
Accuracy -Torque -RPM -Horsepower	 ±0.5 percent of full scale ±0.1 percent of full scale ±0.5 percent of full scale
Operating Force	8 oz.
Frequency response	DC to 400 Hz (3-dB limit)
Temperature range	-10°C (14°F) to 65°C (149°F)
Linearity	0.5% of full scale
Repeatability	0.01% of full scale
Resolution	0.01% of full scale
Effect of time -On reading	 .1% per year
Analog outputs -Torque -RPM -Horsepower -Recorder output impedance	 ±10V scaled/4-20 mA 0 to +10V scaled/4-20 mA ±10V scaled/4-20 mA 1 ohms resistive nominal. 25mA maximum output current
RPM measurement	0 to 100 percent of range (up to 250 RPM)
Shaft size	8 in. diameter minimum. Contact factory for smaller sizes.
Power requirements	115 VAC (±15%), 50-65 Hz. Power consumption 600 VA max.
Magnetic tape output	500 to 5000 Hz - use for recorder and replay
Radiated Emissions -Signal frequency -Power frequency	 10mW 10.7 MHz None

PRODUCT SPECIFICATION – McNAB TYPE MODEL SERIES S10702	
Torque Sensor -Type -Torque tracking (compliance) -Cable connections -Sensor and transmitter weight	 Gage to measure mechanical displacement 1:0.997 Connectors and plug 4 lbs.
RPM Sensor -Type -Resolution -Weight	 Proximity sensor 1/16 RPM 1 lb.
Signal to Noise -Typical signal to noise	 Greater than 40 dB in engine room environment (in practice)
Readout Unit -Displays -Power and input connections -Enclosure -Weight	 ±3½ digits; display switched and functional testing Screw terminals Steel drip proof As required (see proposal dwgs.)
Remote Readout (optional) -Displays -Connections -Mounting	 Six; ±3½ digits; with dimmer Screw terminals (See proposal dwgs.)
System Weight -Typical (with cover)	 140 lbs. per shaft with readout
Manual -Installation, operating, maintenance manual provided (commercial off-the-shelf), drawing package specific to ship.	
Cables -See drawings for cable information. Distance between readout and RPM sensor is 1000 ft. otherwise unlimited. Should be shielded and removed from heavy electrical noise.	

Specifications use McNab procedure S3729.

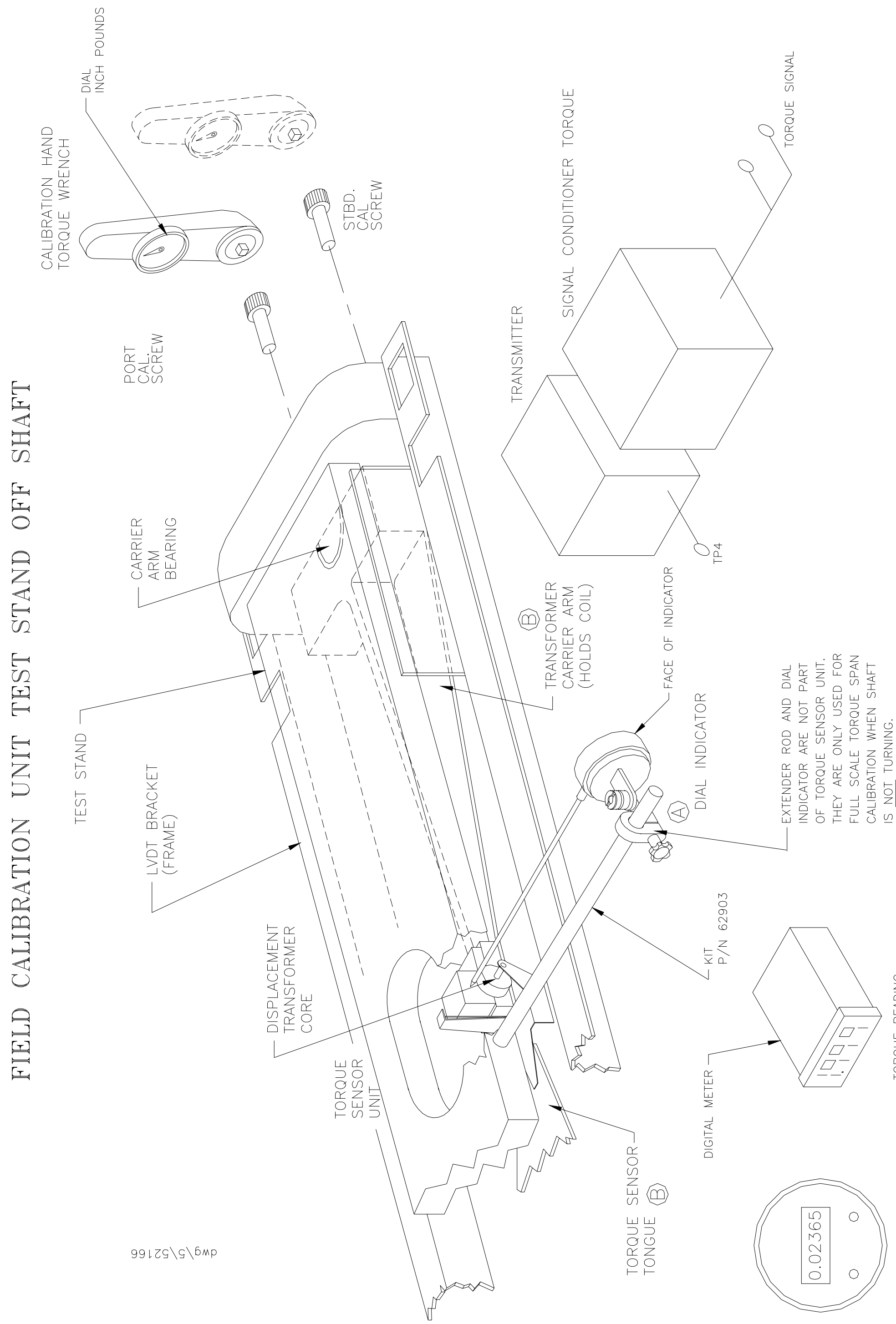
APPENDIX 3, Span Calibration Illustration 62281 on Shaft



APPENDIX 4, Field Calibration at Remote Location

PROCEDURE	RESULT
THE ACCURACY OF THE SYSTEM MAY BE VERIFIED BY THIS PROCEDURE.	THIS IS OFF SHAFT VERIFICATION OF SYSTEMS ACCURACY. (AND QC OF SYSTEM) POLARITY.
OPERATOR IS TO MOUNT ASSEMBLY. AC POWER IS TO BE ON FOR 1/2 HOUR.	
MOUNT DIAL INDICATOR (RESOLUTION .00005”) KIT P/N: 62903-M( )	THIS PREPARES THE UNIT FOR MEASURING THE MECHANICALLY SIMULATED TORQUE TWIST (“d”) VALUE ON TORQUE SENSOR. (SEE SHIP’S CDS.)
ESTABLISH A TEMPORARY CONNECTION VIA JUMPER FROM ORANGE ANT. WIRE TO SIGNAL RECEIVER FOIL. INSERT HEX KEY ON PORT OR STARBOARD SCREW AND BY TIGHTENING UP ON ONE SCREW AND LOOSENING THE OTHER. TEMPORARILY SHORT OUT TRANSFORMER COIL TO SET ZERO ARM POSITION AND TO SET DIAL INDICATOR TO ZERO. SWING ARM (TONGUE) TO THE “d” VALUE. (SEE C.DS.) APPROX. 30mil. (OR FULL SCALE)	THE TRANSFORMER CARRIER ARM WILL SWING ON ITS BEARING CAUSING A SIMULATED TORQUE DISPLACEMENT.
WHEN ADJUSTING THE KEY, LIGHTLY TAP THE ARM.	THIS TAPPING WILL RELEASE POSSIBLE MECHANICAL BACKLASH.
USING THE KEY, SWING THE ARM BACK INTO ZERO POSITION (SET DIAL INDICATOR TO 0.00000) BY GOING PAST ZERO POSITION, REVERSING DIRECTION AND SMOOTHLY COMING UP ON ZERO IN THE DIRECTION WHICH IS THAT TWIST DIRECTION ASSOCIATED TO APPLICATION OF FORWARD SHAFT POWER.	THIS PROVIDES AN ELECTRICAL SIGNAL MATCHING SHAFT TORGUE AND WHERE CALLED FOR AND IN THE RIGHT POLARITY. WHEN THE READING DOES NOT SHOW AHEAD (+) TORQUE VALUE. REVERSE LEADS TO INDICATING METER (OR AS REQUIRED IN CDS.)
CONTINUE TO SWING THE ARM UNTIL THE DIAL INDICATOR SHOWS THE C.D.S. “d” VALUE. (OR PERIOD) FOR SPAN CALIBRATION. REPEAT AS REQUIRED.	THIS MOVES THE TRANSFORMER CARRIER ARM THE MECHANICAL DISTANCE . “d” CALCULATED FOR SPAN CALIBRATION. ADJUST SPAN TO MATCH CDS VALUE.
RETURN TRANSFORMER ARM TO THE ORIGINAL MECHANICAL ZERO AND MAKE SURE PORT AND STBO SCREWS ARE TIGHT. REMOVE CALIBRATION KEY AND DIAL INDICATOR.	THIS RETURNS TORQUE SENSOR TO ITS ORIGINAL POSITION.
RE-CHECK ZERO & TIGHTEN SCREWS AFTER INDICATOR REMOVAL COAT ALL SCREW HEADS AND THREADS WITH VARNISH OR GLYPTAL. DISMOUNT FROM TEST STAND AND MOUNT IN ITS TRAVELLING BAR.	THIS PREVENTS SCREW FROM BACKING OUT.

APPENDIX 4, Field Calibration at Remote Location (Cont.)



APPENDIX 5, Life Testing at McNab (photo)

TORQUE METER LIFE TEST

At McNab, Inc. Facility
Running 24 hours a day for more than
10 years without failure.

APPENDIX 6, Shaft Horsepower Installation