SINGLE TEST CELL FACILITY
TO ACCOMMODATE MULTI-POWER, MULTI-BRAND ENGINES

ABSTRACT

Kenyan Navy desired to upgrade and retrofit their existing PaxmanV16 engine test cell to facilitate load testing and validation of five (5) of their marine engines namely PaxmanV16, PaxmanV18, MTU956, MTU362 and MTU4000. Neptunus Power Plant Services Pvt Ltd was awarded the contract to design and build the test bench engineering system in Mombasa, Kenya.

This paper is aimed at familiarizing the readers with the challenges involved in the design of a single test bench facility and its auxiliaries to equip five marine engines of different rpms and power capacities to perform the load tests and engine diagnostics. The primary obstacle to design such a test bench is to accommodate the large variation in physical size and capacity of the five engines along with the selection of engine control system, base frame, radiators and the auxiliary systems such as exhaust gas, air compressor, fuel, lube, HT, LT, dynamometer (dyno) water pipelines etc. The design has been validated with the structural and mechanical simulations, HAZOP (Hazard and operability procedure) and AERMOD (Air Modelling) analyses.

Neptunus endeavours to build environmental friendly engineering systems. In the same context, the lube system of the test cell is equipped with Europafilter offline kidney loop filtration system to purify the lube up to 0.1microns. The Lube will not be discarded from the sumps after engine testing, it will be filtered and used indefinitely. Original cooling towers were replaced by radiators for all the cooling systems to eliminate water drift, wastewater recirculation and purification system and the exhaust system design with zero downwash are incorporated in this test bench design by Neptunus as a step towards building green test cells.

This paper covers the general considerations, design challenges and solutions of a low cost, multi-engine, multi-power, multi brand test bench. This paper is an overview and does not provide the list of all the components necessary for the construction and operation of such a test cell.

1. INTRODUCTION

A engine test bench is used to test and validate engine parameters such as power, fuel consumption, vibration, noise, crankshaft torque, angular velocity, pollutant concentrations in the exhaust gas, exhaust gas temperature, engine oil temperature and intake manifold pressure mainly after the major overhaul. It houses sensors (transducers), data acquisition features and actuators to control the engine state. Major components of the test bench facility are Hydraulic variable fill resistive type dynamometer, common base frame for engine and dyno, engine water and dyno water cooling systems with radiators, fuel, lube, outlet exhaust and inlet air systems, instrument and power control console.

Dyno is a device for measuring force, moment of force (torque), power, rotational speed (rpm) produced by an engine, motor and other rotating prime movers. Engine-dyno base frame shall hold and arrest its own vibrations during the testing without transfer to the engine or to the engine room. Fuel tanks, lube oil sumps, air inlet sumps and its associated systems are designed with filtration and instrumentation to supply fuel for the combustion of engines, lube for cooling the engine components, compressed air for the engine starting motor and cylinders respectively. Cooling system of the engines and dyno are equipped with radiators for effective heat load management. These open environment radiators are equipped with propeller fans controlled by programmable logic control (PLC). Engine rpm, start/stop for testing can also be controlled from the same PLC.

ENGINE	Power (kW)	Brake Horsepower (bhp)	Maximum RPM	Fuel consumption (g
Paxman V16	2014	2700	1500	126
Paxman V18	2268	4545	1500	141
MTU 956	3200	4500	1575	238
MTU 362	992	1331	1500	60
MTU 4000(Planned)	3440	4613	2100	213.8

Table I: List of Kenyan Navy marine engines

1.1 DYNAMOMETER (VARIABLE FILL TYPE) PRINCIPLE:

Dyno works on the principle of brake water resistance. The Shaft of the dyno coupled to the shaft of the engine will develop a variable resistance (i.e. reactionary torque) as the engine operates. Inside a engine dynamometer, water flow, proportional to the desired applied load, creates resistance to the engine. Continual change in momentum of water, tangential to the direction of rotation of dyno's shaft created during the engine operation, will be balanced by an equal torque reaction through strain gauge load cell connected to the bedplate. The control console shall display dynamometer torque and speed. The adjustment of the dynamometer water flow control valve and engine throttle is by automated electrical actuators.

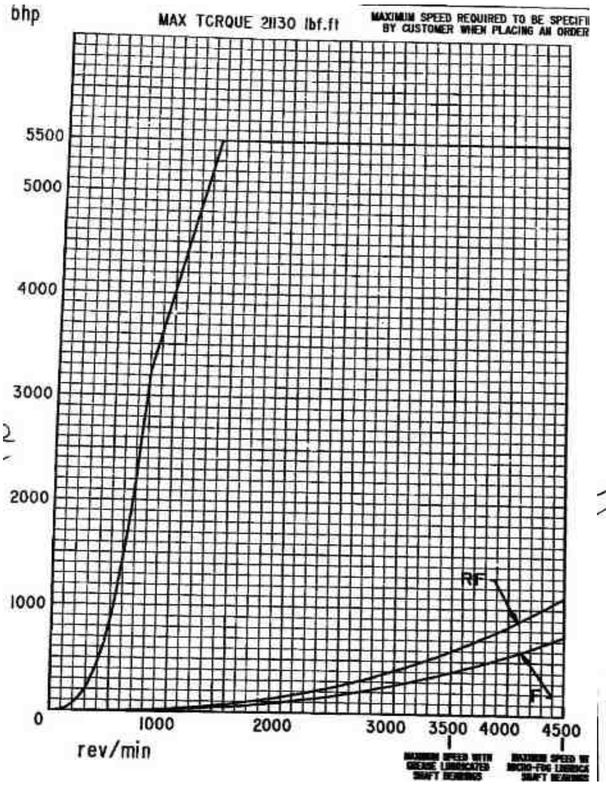

Figure 1: Dyno Power Capacity Curve

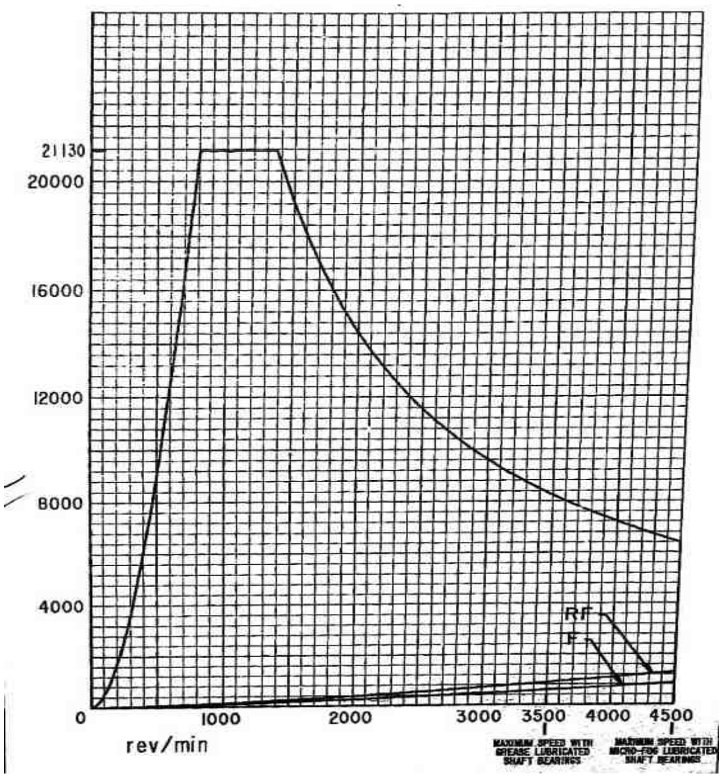

Figure 2: Dyno Torque Capacity Curve

2. GENERAL DESIGN FRAMEWORK:

- Engine test bench designed is capable of dealing with energy flows (Fuel, air, lube, cooling water) that are three times greater than the 'headline'engine rating. Room acoustics, forced ventilation of engine room, compressed air system for engine starting systems are provided in this test cell facility.
- Recirculation and filtration systems provided in the water, fuel and lube oil systems maintain the quality of the systems at required levels at all the stages of the operation. Alfa Laval fuel filtration is provided in the fuel line for effective sludge removal.
- PLC direct communication with the field and engine sensors is established. Accurate engine speed regulation through Woodward 2301A speed controller for electric actuators, pneumatic control via PLC or through geared motor for hydra-mechanical governors is established.

3. DESIGN CHALLENGES:

It is common to find test cells with the capability to test a single engine. There is no standard design to test multiple capacity engines on a single test cell. The challenges in the design and construction of this multi-engine equippable test bench facility against a single engine equippable test facility are as follows:

- As the height and size of every engine are typical and different from each other, design of a single base frame to enable engine shafts and dyno shaft alignment (shafts centre line match) was a design and fabrication challenge.
- As the diameter of the shaft of every engine differ from to the diameter of the shaft of the dyno, design and fabrication of couplings was a challenge.

- As the increase in dyno water temperature beyond 40°C could lead to complications in the operation of dyno, design of dyno cooling circuit to match the typical flow rates of the engines along with temperature control at all the working conditions was a design challenge.
- The design of the exhaust duct was a challenge because of limited existing space available, typical diameter of the outlet of exhaust of five engines, typical height and location of the exhaust duct of five engines from the ground level.
- As the inlet and outlet sizes and locations (height, side of the engine) are typical for every engine, design of the water, fuel, lube, inlet air connections of the test bench facility was design and site construction challenge.
- Management of the quantity, temperature, pressure and quality of the following common circuits were a design challenge - Lube system for efficient engine cooling, fuel system for efficient fuel consumption, fuel-air mixture, Air supply system for engine starting motors and cylinders, Exhaust trunking (pipe) to match to the exhaust connections of all the five engines to enable acceptable back pressure on the engine, cooling water system and radiators for efficient heat dissipation

4. IMPORTANT DESIGN CONSIDERATIONS

The following are the design solutions provided in each system of the test bench facility against the complications envisaged in building the test bench to equip all the five engines.

4. DYNO

Preexisting dyno (Paxman V16 supportable) was refurbished by Neptunus at UK works of Froude Inc. It is fairly easy to choose dyno parameters to suit for the testing of a single engine, whereas, the assortment of the dyno's parameters to suit to the testing of five engines with the four zones of the power and torque capacity curves correctly designed to suit the application was a substantial challenge. Neptunus has also incorporated the below-mentioned changes in dyno design along with the power and torque curve selection to enable the multi-engine load testing.

- Provision of rotachocks against shims on the dyno base frame for height adjustment for shafts alignment.
- As the diameter of the shaft of engines are typical and different from the dyno shaft, five different couplings are custom designed, fabricated and validated to couple the shafts of engines and dyno.
- Butterfly valve is designed and provided over the oil pump of dyno for manual alteration of pressure according to the requirement (engine, operating condition)
- Auto control of the water inlet and outlet valves of dyno is obtained by the use of a temperature sensor at the water outlet, which shall adjust both the valves to maintain the water temperature inside the dyno in the range of 25-60°C.

4.2 BASE FRAME:

- Width and height of engines are typical and proportional to its capacity. Engine-dyno shaft centre line mismatch for all the engines is explained in Figure-3. The figure indicates the relative height of the engines shaft centre line against the dyno shaft centre without additional height adjustment tools.
- Base frame design to accommodate engines of different widths through the brackets for sturdy fitment was a design challenge as explained in Figure-4. The figure indicates the relative width of all the engines having deep sump with all of them fitted to the base frame.

Fig 3: Engine-Dyno shafts relative height representation

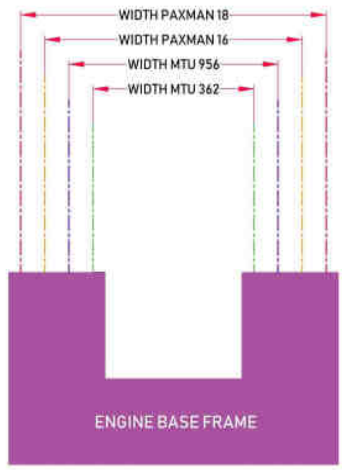

Fig 4: Engines width representation

To overcome the above-mentioned problems in accommodating all the five engines, five different stools are custom designed with brackets on it at common and typical locations for sturdy fitment on the base frame. Stools are equipped over the base frame for height adjustment to match the centreline of engine shaft with dyno shaft.

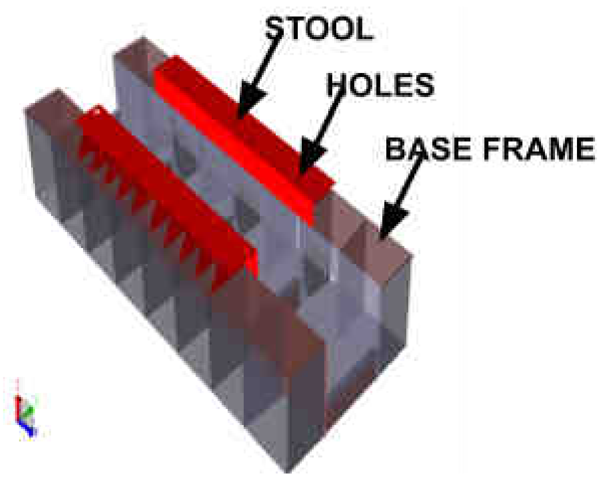

Figure 5: MTU 956 stool and base frame

4.3 COOLING SYSTEM:

Marine engines are cooled with seawater directly or indirectly. Cooling system of this test bench facility built to accommodate the marine engines and dyno contain HT (High Temperature), LT (Low Temperature), dyno water circuits through thermostats, dyno radiators, LT radiators, HT radiators.

The primary functions of the test bench facility cooling system are as follows:

i) Provide HT, LT cooling and recirculation through the thermostats.
ii) Provide auto-cooling and recirculation to the dyno water.

Wastewater shall be stored, filtered and reused. The cooling system of the dyno is also designed with radiators, auto controlled servo valves in the outlet and the inlet of the dyno water circuit controlled by thermostats. Dedicated radiators controlled by PLC shall operate the cooling circuit according to the requirement of respective engines.

4.4 FUEL SYSTEM

Fuel system contains the pumps (booster and transfer), PRVs for heat exchangers in the return fuel line, alfa Laval filtration system with visco mass type flow meter, along with the necessary valves. Functions of the fuel system are to deliver filtered fuel from the fuel tanks to the engine inlet at required flow and pressure, withdraw return fuel into fuel tanks through heat exchangers.

- As the location, pressure, flow and the diameter of fuel inlet pipe are typical for every engine, custom designed flexible pipelines and hose flanges are fabricated to serve every specific engine.

4.5 COMPRESSED AIR SYSTEM:

Supply of compressed air to starting motors is the method of starting of MTU 362, Paxman V16, MTU 4000, Paxman V18 engines. Whereas, supply of compressed air directly to the engine cylinders is the starting method for MTU 956 engine. It would have been fairly easy to supply compressed air to a single engine starting motor, it is complex to design a compressed air circuit to supply clean air to engine starting motors, engine cylinders, MIP unit of the Paxman V18 engine, Dyno bearings at regulated flow and pressure. Neptunus has provided the following in the circuit to accommodate the above-mentioned requirements and provide the compressed air at controlled flow and pressure.

- Pressure switch is provided on the dual stage compressor for manual control of outlet pressure to equip all the engines with the required pressure.
- Air regulator is provided for the control of the inlet pressure of dyno bearings to support the functioning of dyno for the operation of all the engines.

4.6 EXHAUST TRUNKING:

Single engine exhaust trunking is in general designed with the duct size and bends designed to minimize backpressure on the engine. It has been a spatial and complex challenge to design the exhaust trunking to suit the requirements of all the five engines. Moreover, Paxman engines contain two individual exhaust discharge pipes from engine whereas MTU engines have a single discharge duct pipe. Diameter, height and the location of the exhaust duct is typical for every engine. Neptunus designed a common exhaust ducting system to support all the five engines. The exhaust from the engines is designed to be connected to a common connection adapter that houses flanges suitable for inlet connections of all the engines and outlet connection suitable for the MTU4000 (highest load) engine.

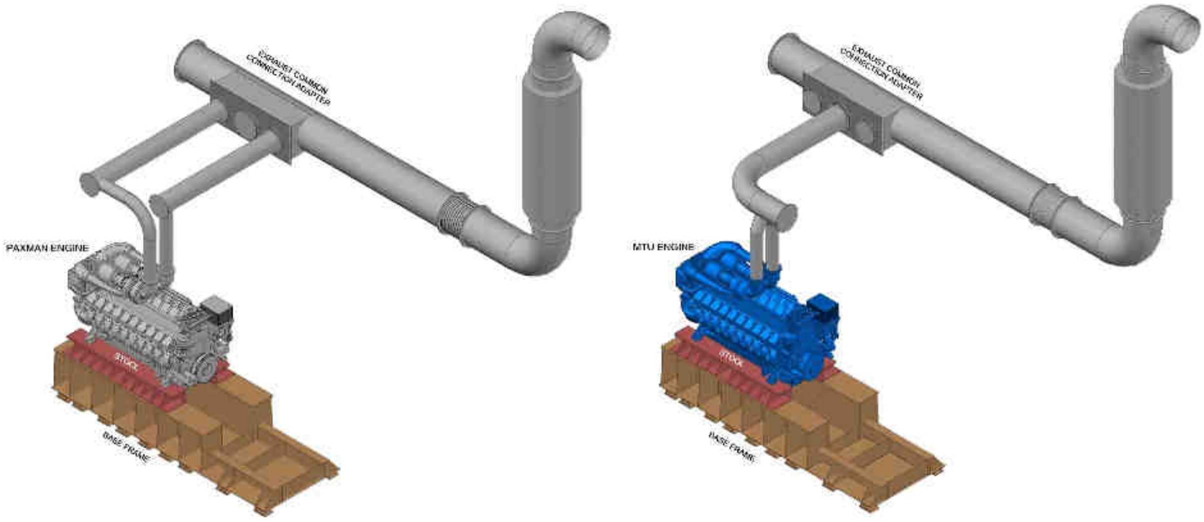

Figure 6: Exhaust trunking for Paxman V16, PaxmanV18(left) MTU 956, MTU 362 (right)

4.7 INSTRUMENTATION AND CONTROL

The instrumentation and control system of this test cell consists of the SCADA (Supervisory control and data acquisition), PLC , Motor Control Console (MCC) , and UPS. Data loss and operational discrepancy are predicted as the risks of the system and the instrumentation of dyno, test bench auxiliaries are chosen to nullify these risks.

- Bypass lines and redundant components are introduced at necessary locations in all the circuits to avoid operation discrepancy during instrumentation failure
- For all the sensors that communicate directly with PLC, parameters shall be recorded in SCADA.
- Remote controlled loading is enabled in the retrofitted dyno design against the pre-existing manual loading through control switch notch for fast and accurate engine testing.
- To avoid overload on the motor drives during testing, overload protection through the dedicated and backup MPCB (Motor protection control board) overload relays are provided in the system.

4.8 EFFORTS TOWARDS THE ESTABLISHMENT OF GREEN TEST CELLS

Neptunus endeavours to build green test cells. The following are the measures enforced in the design as a step towards the build of green cells.

- Europafilter offline kidney loop filtration system to purify the lube oil upto 0.1microns. It is a general practice to discard lube oil after the engine test. In this test cell system, oil shall be completed filtered and reused with biodegradable inserts.
- Use of radiators to replace cooling towers.
- Wastewater recirculation and purification system in the dyno, HT and LT circuits. Even in the case of engine replacement over the base frame, water is designed to be drained into the sump, which will always be reused completely.
- Design of the exhaust system with zero downwash to protect environment and provide required safe breathing levels.

5. DESIGN VALIDATION:

5.1 BASE FRAME:

- The structural stability of the base frame is validated with the structural analysis software; SESAM Genie V 7.1-12 and it was verified that stress on base frame is within the allowable limit.
- Fabricated base frame's ability to hold the dynamic load and vibration of engines is successfully validated at the site (Mombasa, Kenya, Africa).

5.2 EXHAUST:

- The selection of the exhaust duct size, velocity of the exhaust in the pipe, backpressure on the engine is validated with the theoretical calculations. The selection is validated with the velocity simulation through ANSYS and plume rise analysis simulation through AERMOD software. AERMOD analysis confirmed that the dispersion of exhaust is within the acceptable limits of the local environmental norms and is proven to have negligible effect on the residential complex of the Mombasa, Kenya located at around 5 Kilometres from it.

6. SUMMARY

Neptunus successfully designed, fabricated, erected, commissioned and validated the test cell facility to accommodate Paxman V16, Paxman V18, MTU 362 and MTU 956. Neptunus is custom designing the sub-systems of this test cell facility like stools, couplings, hose flanges, exhaust common adaptor plates, circuit orifices etc. to equip this test cell for testing of MTU4000 engine. Neptunus endeavours to build challenging, complicated, green, custom designed test cells for testing and validation of engines with the same spirit in future.

In the case of queries, kindly contact the below mentioned at the provided phone numbers. We would like to hear from you, share experiences with you to better the way test cells are built.

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