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DECARBONIZATION IN IGT DEVELOPMENT: ALIGNING TEST TECHNOLOGY WITH OPERATIONS

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Abstract

MDS is continuously improving its technology offerings that help tackle the emissions challenges being faced by customers either developing IGT's, post repair testing of IGT's and/or those that operate them (IGTs) as a core puzzle piece that drives/propels their business. Technology adoption can be bi-directional meaning that there are technologies that already exist in the marketplace, such as SCR systems, that can be integrated within test facility applications, our core business, to help reduce greenhouse gas emissions. And there are test facility technologies that we believe can be retrofit into legacy compression pumping stations, oil pumping stations and power generation package or any business operating an IGT that can help reduce the impact on the environment. Two examples: 1. replacing natural gas starting systems for IGTs with hydraulic start systems. 2. adding emissions monitoring systems to legacy packages can help proactively determine that the engine is operating very inefficiently, and a repair cycle is needed.

Introduction

Cross-pollination in the realm of engineering and business can take many forms. In the gas turbine validation space, solutions that are relevant and appropriate for aero engines can lend insights into the test environment for industrial power. For example, the philosophy of high velocity, multi-engine throughput that optimizes asset utilization in the industrial test environment, has its roots in aero engine testing. A given test cell is sized for a particular thrust, mass flow and bypass ratio, but can be used for a multitude of engines provided that key performance parameters are respected.

In a similar vein, design developments coming from the test environment can be leveraged in applications related to power generation and pumping. A number of these developments and practices have the potential to propel forward the industry through the integration of ideas that result in decreased generation of greenhouse gases, and in the integration of new fuel sources such as hydrogen.

Given the recent federal government announcement that "inefficient" fossil fuel subsidies will end, there is a strong importance that must be placed on ensuring that the industry as a whole is aligned with Canada's climate commitments.

This paper will explore a number of technologies that are either fully developed or under development in the Validation and Test regime, that stand a chance of adoption in the field. The unifying these amongst these technologies is that there has been exploration in the test environment. These themes are as follows:

- Hydraulic Start: Replacing Natural Gas Starters to Reduce Discharge Into the Environment
- Compressor Gas Seal Recovery;
- High Throughput, Multi-engine Capability;
- Emissions Monitoring;
- Gas Turbine Auxiliary System Effects in Introducing Hydrogen Fuel

Hydraulic Start: Replacing Natural Gas Starters to Reduce Discharge Into the Environment

Gas Turbine Engines require assistance when starting. The typical method uses an external drive at the Accessory Gearbox which, through an internal shaft and gears, spins the HPC until ignition is initiated, and the engine is accelerated to a speed where operation is self-sustained.

The typical method uses an external drive at the Accessory Gearbox, to spin the HPC to a minimum speed by providing a torque input via the engine gearbox. Depending on the application, that external input can be supplied by air/gas starter, hydro-mechanical motor, or electric motor.

At facilities where a sufficient amount of compressed air is available, starting the engine with an air starter is an economical choice. Starting an engine using an electric motor or a hydro-mechanical motor is also common.

In more remote facilities that may not have the same level of infrastructure, starting an engine with compressed air or an electric motor is not practical. For gas turbines installed in pumping and compressor stations on Natural Gas pipelines, the natural gas in the pipeline can be used instead of compressed air to start the engine using the air/gas starter. Natural gas under pressure is used to drive the starter, and the discharged gas from the starter is expelled into the atmosphere.

The amount of natural gas expelled into the atmosphere will vary based on the size of engine/starter, the frequency and duration of the starting cycles. As well as engine starting, the gas turbine/compressor can be “motored” for longer durations for engine intake and exhaust purge, pipeline purge, or IGT compressor wash cycles.

As an example, a gas starter can use up to 186 lb/min (84 kg/min) to achieve the maximum speed need to start an engine. A typical start is accomplished in 45 to 90 seconds, so if a constant ramp in flow is assumed, a typical start can discharge 63 kg of NG into the atmosphere.

When facility pipeline purging is required, the starter may run at partial speed for 35 minutes. If we assume the gas consumption through the starter at even half of the maximum (use 42 kg/min, for example), an estimated 1470 kg of NG is discharged into the atmosphere during such a purge cycle.

Assuming that engine start and purge cycles are infrequent, the relative cost of the wasted NG to the pipeline supplier may not be significant. However, with increased awareness of the importance in reducing greenhouse gases, and in many cases, the implementation of government restrictions on such releases, there is strong incentive to take a different approach for starting engines in these applications.

One proven method for starting industrial gas turbines uses hydraulic power from a Hydraulic Power Unit (HPU) to power a hydraulic motor (with overrunning clutch) mounted on the AGB. Using electronic control on the variable displacement HPU pump, the hydraulic motor speed can be adjusted to complete an engine start or motor the engine at lower speeds and for extended durations without the discharge of natural gas described above. Hydraulic power is typically used in the test environment as it is readily available; it is used for facility processes.

Compressor Seal Gas Recovery

Turbomachinery used in the transportation and storage of natural gas vents a small amount of natural gas through the dry gas seal(s). Although the leakage rate is relatively small, it is continuous during the operation of the equipment. For facilities that maximize operating times, this small leakage rate adds up to a significant amount over time.

For example, if the gas compressor at a pumping station has operates 8500 hrs per year, more than 75,000 kg of natural gas is “leaked” to atmosphere.

While this does represent a loss of a commodity, the release of this much of a potent greenhouse gas can easily exceed government limits for such discharge.

Recovering this gas to either burn cleanly (either through flaring or using as a fuel for a different process), or for re-injection into the process. Since the “process” in the natural gas pipeline is under a much higher pressure than the main vent line for the dry gas seals, any collected gas must be compressed to be able to re-inject it into the process.

Specialized equipment to collect and compress the leaked natural gas for return to the process gas lines can be provided to reduce the cost of lost gas as well as to satisfy governmental limits on released greenhouse gases. In this instance there is no direct correlation to the validation environment – this is more of an observation on how additional technology can be used to reduce the leakage of gases into the atmosphere.

High Throughput, Multi-Engine Capability

Engine test facilities are capital-intensive. Maximizing the utilization of the facility provides the greatest return on investment. Maximizing utilization can be achieved by minimizing the time that it takes to prepare an engine for test, and maximizing the number of different engine variants that can be tested in a given test cell. The connection to decarbonization in this sense is to the initial asset development. A lower number of total assets are required as each asset has a higher utilization.

Aero engine test facilities are designed to test many engine variants in the same cell, and are designed with technology that allows for quick installation times. An engine can be brought in to the test cell and can be up and running in as little as one hour. From an aerodynamic perspective, aero test cells are designed using the ejector effect, which relies on a particular bypass ratio (the ratio of bypass air to engine air). They are also designed for particular thrust loads and fuel flows. As long as these parameters are adequate for a particular engine, the facility can be adapted to run the engine. Typically the engine is suspended from an “adapter” which is engine specific, but has a common interface to the facility. This adapter tailors the facility services and interfaces to the engine. This includes mounting configurations, load transfer, services such as fuel, oil, air start, and instrumentation are fed through the adapter.

To facilitate high throughput, engines are prepared for test outside of the test cell in the aptly named “prep area”. Engine transfer has historically been done overhead with monorails, which transport the dressed engine from the prep area to the test cell. Services are connected to a multi-connector automatic coupling plate which reduces the time it takes within the test cell to connect all services.

This philosophy has been transported to the IGT test space. Engines are dressed to “adapters” in the prep area, and then brought in and quickly connected to services via coupling plates. An added complexity in an IGT facility is the alignment to the load. Features within the test cell that are used to restrain the engine adapter are configured such that the alignment tolerances on these are tighter than what the coupling alignment requires. Once these features have been installed and the engine aligned to the generator, repeat alignment is typically unnecessary. There are known instances of test cells going for multiple decades without realignment. Where possible, splined shafts are used to further decrease the amount of set up time that is required. Various delivery mechanisms and docking mechanisms have been developed over the years, to ensure reliable and repeatable alignment. The systems for docking the engine adapter to the test cell as well as connecting the coupling plates together tend to be powered hydraulically.

IGT engine packages tend to be bespoke designs for a particular engine and variant and tend to be optimized around minimizing size. Engine installation is cumbersome and time intensive. This is usually not a problem provided that there are no service issues with the engine, and that the engine does not require unplanned removal. Upgrading the installation methodology, and upgrading the docking features of the engine package would allow for reduced docking installation time and would allow for a shift in thinking towards performing major maintenance outside of the engine package, and would also streamline the replacement of engines should a problem occur. Standardization of the engine package for multiple engine variants would also allow streamline maintenance and training and reduce the amount of spares necessary.

From here, a further leap to modifying/designing engine packages to facilitate engine test/troubleshoot is possible. Given our increased reliance on electric power, it would make sense that IGT based power could provide easy backup in instances where electrical infrastructure falls down. The technologies listed above are prime candidates for facilitating the rapid deployment of emergency power through IGT's.

Emissions Measurement

Typically for legacy compression stations, emissions statistics are calculated based on other engine parameters. These require a number of assumptions to be made, and as equipment ages, there are variables in these assumptions that are unknown. To provide accurate data, Continuous Emissions Measurement Systems should be considered.

Continuous Emissions Measurement Systems are typical on all development and MRO test cells for IGT's. Experience began with aviation, with engines that power commercial aircraft are required to meet certification requirements driven by regulations. In addition, OEM's have their own specific requirements which are performance based, which must be met. Measurement probes are installed in the gas path of the exhaust and data is collected.

The types of substances that are measured: smoke and gaseous emissions. For gaseous emissions, the following is typically measured using various instrumentation: unburned hydrocarbons (HC), Carbon Monoxide (CO), Oxides of Nitrogen (NOx), Carbon Dioxide (CO_2), and Nitrous Oxide (NO).

CEMS could provide definitive value in the form of more accurate reporting for governmental or regulatory bodies, and for corporate reporting. From a corporate perspective, the data can be used to assist internal finance groups with tackling carbon taxation, assist with maintenance planning and spending, tracking IGT efficiency, trending, and longer-term planning in terms of where to target efforts and future spend. In the test environment, many OEM's configure their analysis equipment to be mobile. This allows a single set of equipment to be shared across a number of sites. This could be considered a cost effective measure in the oil and gas industry.

Gas Turbine Auxiliary System Effects in Introducing Hydrogen Fuel

The introduction of hydrogen fuels in industrial engine test creates new storage and handling engineering challenges: Identifying the fuel delivery configuration for testing, managing risk of explosions and fires, specifying special equipment and instrumentation, material compatibility issues, and access to hydrogen in sufficient quantities.

Let us first identify the fuel delivery configuration for testing. Shown in Figure 1, for a test cell, the hydrogen fuel is stored and blended into a natural gas stream. It is then supplied to either a gas turbine or a gas turbine sub-component such as a combustion rig test article. Novel equipment such as a liquid hydrogen storage tank, cryogenic pumps, vaporizers, and blending rigs are required. This configuration would be similar for any gas turbine engine sub-station with access to hydrogen and requiring a particular fuel blend composition of hydrogen to natural gas.

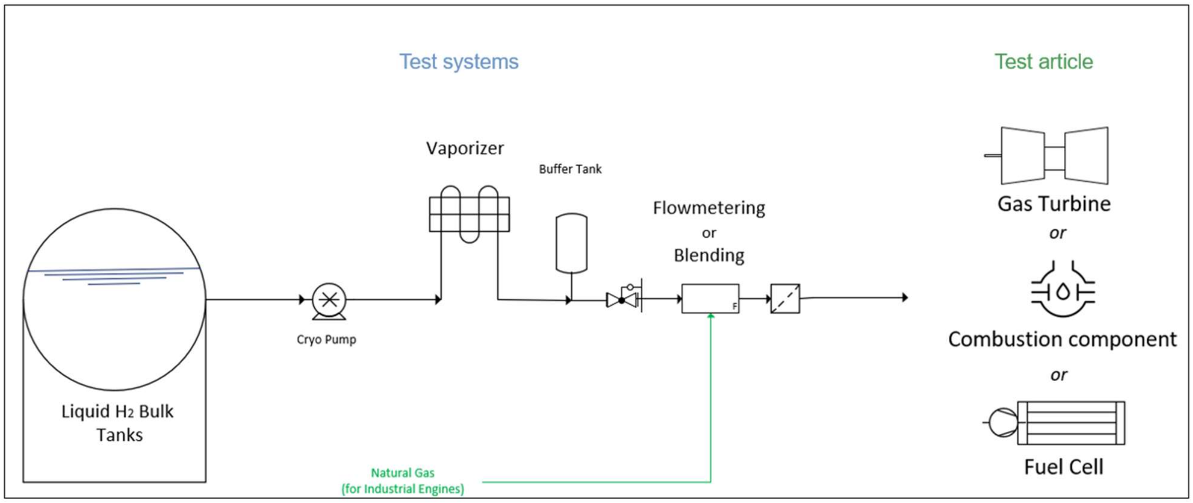

Figure 1: Typical hydrogen fuel test delivery system

The safe integration of the hydrogen delivery system requires a **multidisciplinary approach** in compliance with established codes: considering hydrogen process piping and equipment, building systems, controls, and safety engineering.

Although gas turbine specific standards such as ISO 21789 are not yet fully accounting for hydrogen fuels, **jurisdiction, codes and standards** for the wider industry (such as oil, gas, and chemical) are available and developed because they have handled hydrogen for decades. For example, NFPA 2 in the US and Canada is a hydrogen-specific code already referenced by some jurisdictions [8] such as OSHA 1910.103 in the US (the author has better familiarity with US-based jurisdiction). As hydrogen is considered a flammable gas or liquid, jurisdictional controls such as the OSHA Process Safety Management of Highly Hazardous Chemicals 29 CFR 1910.119 are enabled for storage quantities exceeding 10,000 lbs of hydrogen. In this case, documentation such as process hazard analysis (like HAZOP), facility siting studies (elaborated below), emergency and operating procedures, and process datasheets, must be recorded and audited on a regular basis. Furthermore, the local fire protection authority having jurisdiction must typically provide final permits with the above documentation in-hand before operation may begin.

A review in **safety engineering** approaches in hazardous area classification, enclosed space risk assessments, and storage safety distancing are indispensable.

The purpose of **hazardous area classification** is to limit the risk of igniting a gas fire by identifying areas prone to flammable gas leakages and controlling the sources of ignition. Hydrogen in comparison with Natural Gas induces larger, more frequent, and more severe hazardous zones because of the molecule's lower flashpoint, higher dispersion rate, increased likelihood of leakage, and lower minimum ignition energy [9] amongst other properties. As a result, hydrogen's gas group severity is classified as gr. B the most severe and hazardous zones can span 15 ft. away from a source of release whereas natural gas is gr. D [10]. The instrumentation and electrical equipment located in these areas must be rated accordingly for safe operation and to meet most regulatory bodies.

The **risk of a detonation or destructive deflagration** in enclosed spaces is also increased where hydrogen exists since it has a higher fundamental flame velocity in addition to other properties mentioned above [9]. In a test facility, the room where the test is taking place, or even the exhaust transferring the flue gas, can all constitute an enclosed space. A detonation largely occurs when the flame front accelerates to supersonic speeds through an opening in the enclosure creating damaging shockwaves, whereas a destructive deflagration's flame front remains at subsonic speeds but still creates in pressures above the allowable pressure in the enclosure. To mitigate both, the enclosure must be designed for deflagration prevention and/or for a safe deflagration based on the risk assessment. This is done by allowing the flame front to safely vent below critical thresholds by for example: specifying deflagration panels, increasing the local ventilation, employing leakage monitors connected to the fuel supply safety shut-off system, and designing the enclosure wall to withstand the event following codes like NFPA 68 & 69. Opting for an outdoor test stand where there are no enclosed spaces can minimize the risk of detonation entirely whereas limiting personnel access during test mitigates the consequences. In addition, for gas turbine test cells, the risk of blade-off events and resulting hydrogen piping rupture should be considered.

The last safety engineering aspect is evaluating **storage and venting safety distances** to prevent collateral damage or harm. Codes such as NFPA 2 provide recommendations for maintaining gaseous or liquid hydrogen bulk storage distances to places of public assembly, buildings, other flammable, or combustible liquids, and more. As a result of several hydrogen properties which increase the risk of a storage tank event, the stricter storage distances between an identical volume of liquid hydrogen bulk storage tank and kerosene are exemplified below.

Overall, regulatory bodies such as OSHA PSM 29 CFR 1910.119 recommend a facility-siting-study to assess and model the risks (likelihood as well as consequence) of events to personnel resulting from a fire and explosion.

Table 1
Comparison of storage safety distance between liquid hydrogen and Kerosene per NFPA 2

$12m^3$ of storage	**Safety distance from a sprinklered combustible building**
Kerosene	4-6 m [11]
Liquid Hydrogen	15 m [12]

The test fuel system **process design, piping, equipment, and instrument selection** are also affected by the introduction of hydrogen. Amongst others, some effects of integrating hydrogen fuels for test are outlined below:

Table 2
Some process design, piping, equipment, and instrument selection effects

Item	**Effects of introducing hydrogen**
Line sizing	• Must be assessed for increased volumetric flowrates for an identical engine power leading to larger lines. Challenge is somewhat offset due to hydrogen's lower sonic velocity which limits the risk of sonic choking in the lines or orifices and minimizes acoustic issues.
Mechanical equipment	• Cryogenic storage vs. compressed gas should be traded-off, where cryogenic storage is typically more cost effective for larger quantities. Both options are largely available in North America from the main producers. A 1-2% daily boil-off rate should be accounted for cryogenic storage. • A hydrogen-natural gas blend rig is required to blend the two streams at a desired volumetric ratio suitable for engine consumption. The primary method of composition control is by flow metering each stream with perfect-gas law volumetric correlations, downstream a gas analyser such as Raman Spectroscopy can provide a high accuracy composition validation within a minute. The engine fuel governor control system must adjust for the varying fuel composition (and varying fuel calorific value).
Material and piping selection	• Hydrogen presents a risk of hydrogen stress cracking. Most stainless steels are suitable for all temperature ranges, some carbon steels are also suitable at room temperatures per ASME B31.12. • The flanged connections should be minimized where possible especially indoors since they constitute a source of leakage. Industry codes like ASME B31.12 provide material selection, piping design, and testing guidance for piping.
Instruments	• Instruments to monitor test parameters such as flowmeters, temperature & pressure sensors, are mostly available at cryogenic temperatures and in NEC Gr.B zones (although can considered special orders).

Item	Effects of introducing hydrogen
	• Gaseous hydrogen flow can be more difficult to monitor unless with Coriolis flowmeters due to exceedingly high velocities or variable methane-hydrogen blend compositions and densities. • Conventional emissions measurement equipment can measure water content and NOx creation. Catalytic LEL gas detectors should be specified at leakage points, conventional IR sensors is only suitable for hydrocarbon fuel detection.
Electrical equipment selection	• Electrical equipment such as a load absorption electrical generator can be specified for Gr.B zones. Hydrogen has been an industry accepted medium of generator cooling for decades.

Conclusion

As we move towards fulfilling our mandates to net-zero carbon emissions, the technologies on which we have converged will change. This change creates intense opportunities for technological development, and this growth will find inspiration in many places. There is a strong alignment between technologies in the aero space (the idea of the aero derivative quickly comes to mind) and in the Industrial Gas Turbine space. Crossover between these two is evident in the technologies that have been developed for the validation of both industries. The test environment is a good breeding ground for the innovation necessary to transform our industries to reduce our overall environmental impact.

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