Upgrading, monitoring and operating a dome drive system
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ABSTRACT

CFHT’s decision to move away from classical observing prompted the development of a remote observing environment aimed at producing science observations from headquarters facility in Waimea, HI. This remote observing project commonly referred to as the Observatory Automation Project (OAP) was completed at the end of January 2011 and has been providing the majority of science data ever since.

A comprehensive feasibility study was conducted to determine the options available to achieve remote operations of the observatory dome drive system. After evaluation, the best option was to upgrade the original hydraulic system to utilize variable frequency drive (VFD) technology.

The project upgraded the hydraulic drive system, which initially utilized a hydraulic power unit and three (3) identical drive units to rotate the dome. The new electric drive system replaced the hydraulic power unit with electric motor controllers, and each drive unit reuses the original drive and swaps one for one the original hydraulic motors with an an electric motor. The motor controllers provide status and monitoring parameters for each drive unit which convey the functionality and health of the system. This paper will discuss the design upgrades to the dome drive rotation system, as well as some benefits, control, energy savings, and monitoring.

Keywords: Remote Control, remote monitoring, dome drive system, hydraulics, variable frequency drive, RS 232 serial interface, reduced electrical consumption, improved reliability

1. INTRODUCTION

The original hydraulic dome drive system, which is used to rotate the dome, utilized a hydraulic power unit, with 300 gallon capacity. Two identical parallel motor/pump systems, pumped hydraulic fluid up 5 floors to three (3) drive units located on the observing floor. The drive units consist of three (3) hydraulic motor assemblies coupled to a drive train containing a planetary gear reduction box, an output shaft, and a 24” diameter steel wheel coated with rubber to achieve a friction drive system.

The new electric dome drive system replaced the hydraulic power unit with a variable frequency drive electric motor controllers. It reused the drive-train minus the hydraulic motor which was replaced by a VFD electric motor and mounting adapter. Using the motor controller parameters, information such as torque, voltage, and speed were available to convey the current functionality and health of the system. RS232 serial interface cables communicate real-time feedback status and monitoring information. Notifications, such as, alerts and warnings are sent out to staff in the form of text messages and emails when abnormal conditions in the system occur.

The benefits from this option not only achieved a remotely controlled system with real-time feedback, status, and monitoring capabilities but it improved reliability, decreased maintenance, increased system efficiency, reduced electrical consumption, reduced the environmental footprint, increased dome tracking speed, and increased the longevity of the observatory by incorporating future dome mass upgrades in the final design.
2. DESIGN

2.1 Upgrade requirements

The intent of this section is to provide a brief description of the design solution to operate the dome system with electronic drive units. It will touch on the requirements for the system, changes to the existing system, interfaces, modifications, benefits, and energy savings of the final system design.

   a) Remote operation The Dome drive system must be capable of being operated in a “safe” reliable manner by means of remote control from a remote location other than the observatory.
   b) Remote monitoring and status The electronic drive system shall provide necessary status, system information, and remote monitoring of the health and operation of the system.
   c) Manual control The drive system control panel must allow for local control of the drive system.
   d) Preventative maintenance The dome drive system shall provide access to all serviceable components and minimize the need for scheduled maintenance.
   e) Improved Reliability The new electronic dome drive system should increase the reliability and minimize repairs.
   f) Safe Interlocking The dome drive system shall provide safety interlocking to prevent unauthorized remote control of the drive system. It shall protect personal and other critical systems when/if other systems shutdown or malfunction.

2.2 Original hydraulic drive system

The dome rotational control system consists of three (3) drive units positioned 120° apart around the track circumference on the 5th floor observing level, which supports the observatory building dome. A central hydraulic power unit, located on the first floor, supplies the necessary flow of hydraulic fluid at a peak pressure of 1800 PSI to the hydraulic motors on the 5th floor observing level.

Figure 1. Hydraulic power unit – 300 gallon reservoir, pumps, motors, and plumbing
2.3 Drive system modifications

Once the hydraulic system was fully understood and the feasibility study was completed, various options were compared and the upgrade requirements were finalized. Baldor motor controllers and motors were chosen as the heart of the new system upgrade to retrofit the original hydraulic system to an electronic system.

The retrofit consisted of replacing the hydraulic power unit (motors, pumps, fluid, and lines) with a set of electronic motor controllers to reproduce the original drive train input power required. The hydraulic motors were replaced with electronic motors that would provide the same output torque values which achieve the identical dome rotating speed.

2.4 Motor Integration

The Hydroland hydraulic motor coupled directly to the drive-train on each of the three drive units was replaced with a Baldor ZDFRPM21204C RPM AC series electric motor, motor adaptor, and motor output shaft coupling.
Some advantages of the RPM AC motor is the compact size, enclosed case, and optimized performance with longer life on frequency power. These motors are specifically designed around packing maximum torque into a small enclosed motor frame size. These motors remove the need to modify the safety frame around the drive units and eliminate modifications to the gear reduction box interface.
To install the new electric motors on each drive unit, the supply and return hydraulic lines were valved off, the lines were removed from the hydraulic motor, drained, and capped. The hydraulic motor was unbolted from the reduction box and set aside. The new electric motor was attached to the gear reduction box via an adaptor kit manufactured by the original manufacturer of the gearbox, Brevini; therefore no additional drive train modifications were required on the three (3) dome drive units.

![Design solution – Modified gear train](image)

**Figure 4: Dome drive geartrain modifications**

### 2.5 Motor controller Integration

The hydraulic power unit (on the 1st floor) was replaced with a drive system cabinet consisting of the electronic motor controllers (drive units). There is one motor controller assigned per motor per drive unit. The motor control units provide the necessary output to the motors to achieve the speed and torque required. The motor controller units will also provide information for remote operations, status, and monitoring such as motor current, motor torque, motor speed, etc. To eliminate heat from the dome observing environment the electronic motor controller cabinet was installed on the 4th floor instead of the 5th floor.
The drives are Baldor 22H Line Regen Vector AC motor controllers which are designed to use the energy or power when a motor is coasting to a stop or becoming a generator, and put the energy back onto the incoming power line by shunting through a dynamic braking resistor. This is a beneficial feature as our duty cycle for the dome rotation consistently results in a total cycle time devoted to braking the motor/load to a stop on every commanded movement.
Figure 6: Motor controller retrofit

2.6 Benefits

Table 2. Upgrade benefits

<table>
<thead>
<tr>
<th>Beneficial Features and Improvements</th>
</tr>
</thead>
</table>
| - Increased rotational speed capability from  
  - 60deg/min to 72deg/min    |
| - Increased system efficiency  
  - Hydraulic system $\eta \sim 30\%$  
  - Electric system $\eta \sim 92\%$  |
| - Reduced electrical power consumption |
| - Reduced Environmental footprint |
| - Eliminate EPA leak risks, personnel leak hazardous   |
| - Hawaii energy rebate   |
| - Reduced mechanical maintenance    |
|  - $\$10k$ savings annually, currently spent on maintenance. |
| - Nominal cost difference between other upgrade options |
| - Reliability  
  - Can operate with one drive out of service  |
| - Designing for the future  |

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2.7 System monitoring and status

The electric motor controllers provide status feedback via communication by a serial interface expansion card, and RS232 cables, and a Pearle device which gathers system information from each motor controller. The data information for each motor controller is logged on an internal status server which provides feedback regarding the functionality and health of the drive system. Outputs such as motor torque, horsepower, drive current, and motor speed are just a few examples of parameters read real-time, stored, and plotted by means of graphs, tables, and plots. This information can be viewed remotely from any web browser to assist the technical staff or remote observers with troubleshooting, diagnosing, or understanding current operating conditions. It also provides valuable statistics regarding operation over the lifetime of the system which can be used to predict failures from abnormal trends.

![Motor Controller Drive Voltage](image1)

![Motor Controller Drive Current](image2)

![Electric Motor Load](image3)

Figure 7: Motor controller system status information – plots can be zoomed real-time to increase resolution

Internal high level and low level software developed by CFHT’s, Tom Vermeulen and Grant Matsushige, monitor outputs as well as internal information on each drive unit controllers and will alert the technical staff to abnormal operating conditions such as a drive fault, motor current or torque above a preset threshold.

3. ENERGY SAVINGS

3.1 Scope

The intent of this section is to provide a brief estimation of the electrical savings gained from the upgrade and a performance comparison regarding the electrical efficiency of the two systems.

3.2 Electrical consumption comparison

Providing a single realistic number gain for the difference between the two systems, hydraulic and electric, is not as easy as it sounds. The complications first arise when you look at the data for nightly observations, each night the dome is rotated a different number of times, some nights the observatory is shutdown due to weather, therefore no rotations take place and other nights the observations require long exposures and some night’s short ones. To complicate this further...
each dome rotation or move results in a different amount of rotation of the dome depending on the target and how far it is away from the last one observed. The amount of work required to provide accurate statistics is astonishing, and after much work, it could still be inaccurate; therefore I will be comparing full (360°) rotations of the dome, an operation both systems share identically at each commanded occurrence.

By comparing full dome rotations for each system, hydraulic and electric, the overall electrical consumption difference and efficiency gain can be clearly seen. This is basically an apples to apples comparison without the statistical complications. From the plot comparisons further on in the document, the following information can be collected.

Table 3. Hydraulic and electric dome drive systems

<table>
<thead>
<tr>
<th>Before</th>
<th>Comparison Chart</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hydraulic vs. Electric Dome Drive Systems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Avg Power Factor (unit less) Average Real Power usage (Watts)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Idle Slewing Idle (ready-not moving) Slewing (one full rotation)</td>
<td></td>
</tr>
<tr>
<td>Hydraulic</td>
<td>0.63 0.71 (P) 10,500 Watts</td>
<td>(P) 28,500 Watts</td>
</tr>
<tr>
<td>Electric</td>
<td>0.73 0.95 (P) 1450 Watts</td>
<td>(P) 6850 Watts</td>
</tr>
</tbody>
</table>

Table 4. Hydraulic and electric dome drive system comparison

<table>
<thead>
<tr>
<th>Values listed are instantaneous values from plots</th>
<th>Comparison Chart</th>
<th>Hydraulic vs. Electric Dome Drive Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Apparent Power usage (Watts) Overall Improvement</td>
<td>Idle Slewing (one full rotation) Idle Slewing</td>
<td></td>
</tr>
<tr>
<td>Idle (ready-not moving) Slewing (one full rotation)</td>
<td>(S) 17,000 Watts</td>
<td>(S) 38,000 Watts</td>
</tr>
<tr>
<td>(S) 1985 Watts</td>
<td>(S) 7250 Watts</td>
<td>8.5</td>
</tr>
</tbody>
</table>
3.3 Plots and power factor

The figures below are arranged to show the hydraulic system before the upgrade and the electric system after the upgrade. The plots have been scaled and fitted proportionally in an attempt to align the initial startup, idle time, and slewing occurrences. The only slight difference between the comparison plots is for the hydraulic drive system, four rotations are shown, and on the electrical drive plots only three moves are shown. This should have no impact on the evaluation.

From figures 8 and 13 below the real power (P) or true power is plotted; the real power is the capacity of the circuit to perform work in a particular time. Without reference to the phase angle, it is the power needed for the required load with no losses at all in efficiently distributing the power to the system. Since the real power is basically the current and voltage of the circuit it is not fair to comment on the improvement during this process, but an overall energy reduction is noticeable.

![The Power Triangle](image)

**Figure 8. Power factor plot**

In Plots 9 and 10 the apparent power (S) consumed is plotted, the apparent power is the product of the current and voltage in the system and includes line inefficiencies. Thus these plots include the line loss from the power factor. They show the product of the real power and the power factor. The plots depict the increased energy needed for the load due to the fact that the circuit requires higher current due to the loss in the distribution system, it is the power drawn by the electrical resistance of the system performing work. This is the amount of overall energy we are billed for.

The average instantaneous values from the plots can be found in table 5. Note all values listed in the table are taken from the plots and do not directly reflect the product of the real power and power factor. The electric drive system reduced the electrical consumption of the system 8.5 times lower during idle and 5 times lower during slews. It is clear that the improvements stem from a reduction in energy consumption and also an improved power factor.
Figure 9. Hydraulic Dome Drive Power Unit survey - Real Power (watts)

Figure 10: Electric Dome Drive (VFD) survey - Real Power (watts)
The power factor is the cosine of the phase angle (θ) between the voltage and current. Power factor is defined as the ratio of the real (true) power flowing to the load over the apparent power in the circuit. The dimensionless number reaches
maximum efficiency or unity at 1, a high power factor reduces transmission losses and improves voltage regulation at the load.

\[
\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}
\]

Figure 13. Power factor equation

In an attempt to determine the amount of time during the night that the dome is at idle or slewing, TCS engineer Bill Cruise was consulted. Using dome data collected nightly, an average operation time of 10.73 hours per night was estimated.

Table 5. Nighttime operating statistics

<table>
<thead>
<tr>
<th>Dome Drive Operating Statistics</th>
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<tbody>
<tr>
<td>Data obtained from TCS movements from Jan 1, 2011 to Sept 26, 2011</td>
</tr>
<tr>
<td># of Nights</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Manual control not included</td>
</tr>
<tr>
<td>240</td>
</tr>
<tr>
<td>Hydraulic system</td>
</tr>
<tr>
<td>98</td>
</tr>
<tr>
<td>Electric system</td>
</tr>
<tr>
<td>140</td>
</tr>
</tbody>
</table>

Operation time refers to the start and end of observing for the night and hence the amount of time the drive system is operating. From estimations by Bill, during nighttime operation the dome is at idle 94% of the time, and slewing ~6% of the time. Fortunately the energy efficiency improvements for the dome drive bias a benefit during idle operations more so than slewing, this development was a surprise benefit of the new system.

The following plots are energy consumption plots from HELCO, Hawaii Energy Company, the provider of our electricity at the observatory. Plot 14 shows the amount of overall energy used for the entire building for a 24 hour period with the hydraulic dome drive system operated. The average observatory load during nightly operations is approximately 157 KW with a maximum load of 159.7 KW.
The next figure again depicts the overall energy usage for the entire observatory but now with the electric drive system operated during nightly observations. It is the very first night of operations with the electric drive system, on April 28th, 2011, since no changes to other systems were made during the week, influences from other load demands or reductions should be negligible.

From figures 14 & 15 the overall energy reduction for the facility is discernible. The average observatory load during the nightly operations is approximately 138 KW with a maximum load of 141.50 KW. The difference between hydraulic drive and the electrical drive during operation are shown below.
3.4 Comparison

The upgraded electric dome drive system has reduced the amount of energy consumed at the observatory during day and nighttime observations. The cost of the electric dome drive upgrade was approximately $96,958.18, total budget costs for the upgrade were provided by Jane Rodgers (CFHT accounting). The pricing from HELCO for our electricity at the summit ranges from $0.35-0.40 per KWH, but this is highly dependent on the peak demand charge in the last eleven months, which consequently the electric drive system has moved downward. But if one assumes a conservative average of $0.375 a KWH operating rate, a difference or reduction of 19 KW, and an average operating time of 11 hours each night. The dome drive system saves approximately $78.00 per average night. The telescope’s nightly operations are highly dependent on weather and equipment failures, some estimates from Christian Veillet (former director), average the observatory down time due to technical problems (2%) and weather combined for a total average of about 30%. That means only 255 nights out of the year the drive system is operating and therefore saves about $20k ($19,985) per year, therefore the upgraded electric drive system should pay for the costs of parts and materials to implement the system in 5-6 years or less due to conservative estimates. However CFHT applied for a rebate with the Hawaii Energy program for the upgrade project and was awarded ~$11K which further reduces the overall cost and payback time. These savings do not take into account the costs for internal labor and salaries.

4. CONCLUSION

The risk of operating the hydraulic dome drive system with components no longer manufactured or obsolete, the rising costs of maintaining an aging system, and the rising costs of electricity, were strong motivators to upgrade the system. Converting the existing system to an electric motor drive system reduces electrical consumption, diminishes preventative maintenance and repairs, frees up internal manpower obligations, and eliminates environmental impacts which are all operating costs associated with operating the hydraulic system.

The annual estimated electrical savings by converting to the electrical system is quite substantial, if one includes the cost of routine preventative maintenance, manpower, and the cost for parts and supplies we would see a payback for the cost of the system returned in less than 4 years. It has also reduced the amount of maintenance required to maintain the system, eliminated hydraulic fluid leaks, freed up manpower, and provided a reliable remotely operated and monitored drive system.

In addition to the time and money savings, there are additional benefits. Dome seeing studies have revealed heat sources to be a major contributor to the degradation of seeing in our dome. The lower consumption of electricity will result in smaller amounts of heat generated in the dome and the motor controllers which are the largest heat generators in the system will be kept off the observing floor. Another benefit to safety and personnel is one less hydraulic system at the summit which could result in injury or environmental impacts from a leak or spill.

The electric dome drive has been operating since 4-28-2011 with only two (2) failures, both electric motor failures, which when sent back to the motor manufacture were deemed manufactured defects and replaced free of charge. These instances resulted in no down time for observing and required only about 2-4 hours for the motor swap out.

ACKNOWLEDGEMENTS

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