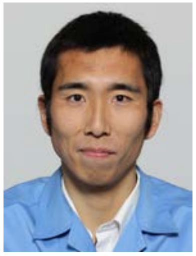
ASIA TURBOMACHINERY & PUMP SYMPOSIUM
12-15 MARCH 2018
SUNTEC SINGAPORE

Conventional servo system to Direct drive Actuators Why does it matter?

Mayank Jain
Engineer, Turbine Engineering & Design Section
Mitsubishi Heavy Industries Compressor Corporation
Hiroshima, Japan

Mayank Jain is Engineer, Turbine Engineering & Design Section, Mitsubishi Heavy Industries Compressor Corporation, Hiroshima, Japan. He has 1 year experience as a turbine engineer. Mr. Jain has B.Tech degree in Mechanical Engineering from Indian Institute of Technology (IIT), Kanpur, India.



Kenichi Nishiyama
Engineer, Turbine Engineering & Design Section
Mitsubishi Heavy Industries Compressor Corporation
Hiroshima, Japan

Kenichi Nishiyama is Engineer, Turbine Engineering & Design Section, Mitsubishi Heavy Industries Compressor Corporation, Hiroshima, Japan. He has 7 years of experience as a turbine engineer. Mr. Nishiyama graduated from Tokuyama College of Technology (Mechanical & Electrical Engineering).

Kyoichi Ikeno
Manager, Turbine Engineering & Design Section
Mitsubishi Heavy Industries Compressor Corporation
Hiroshima, Japan

Kyoichi Ikeno is Manager, Turbine Engineering & Design Section, Mitsubishi Heavy Industries Compressor Corporation, Hiroshima, Japan. He has 19 years of R&D experience for mechanical drive steam turbines.
Mr. Ikeno has B.S. and M.S. degrees in Mechanical Engineering, Miyazaki University and Kyushu University, respectively.

ABSTRACT

This paper discusses the development of Actuators over a period of time. The purpose of an Actuator (servo system) is to operate steam turbine control valves. With the increasing demand for better control of steam valves and depleting support for conventional servo system, there has been a gradual shift to Direct drive Actuator.

The conventional servo system consists of an E/H Actuator along with pilot valve, power cylinder and a complex system of linkages. The introduction of direct-drive actuators enables the Turbine OEM's to completely eliminate the application of pilot valve and power cylinder and redesign the system for less space, better reliability and low maintenance.

The major issue with conventional system is the large number of bearings, linkages and moving parts which had resulted in multiple failures over time and the complexity of the system which makes it very difficult to analyze the root cause of these failures. This paper presents the above failures and how the direct-drive actuators solves the issue by allowing OEM's to design the system with minimum components and better analyze the system leading to high reliability and better optimization of the limited space around Turbine. This paper also discusses other factors which make the system highly reliable and redundant.

While the users experience many benefits, it is also important to understand the issues associated with direct Actuators. The paper also lists these disadvantages along with the remedial measures that can be taken to solve the problems.

INTRODUCTION

The goals of manufacturers and users of industrial steam turbine systems are generally well aligned: High availability and reliability, low performance degradation, and low maintenance requirements are high on list. Cost and space requirements often play important roles.

Over the last few years, the Turbine manufacturers have seen a gradual shift from conventional servo system to direct drive Actuators. This shift can be observed due to higher reliability and better overall process control of direct-drive Actuators but many users are still hesitant to use them due to the limited information available on the subject. Lack of long-term experience of Direct-drive Actuators in the industrial turbines also adds to the hesitancy of users. Examined closely herein are the characteristics of a conventional servo system and the benefits of direct actuator over them. Many of these factors may seem small but can loom large in some failures. Losing control of the Turbine can be catastrophic. A servo system should be designed to control the Governing Valve precisely and quickly respond to loss-of-load or emergency shutdown events. Precise and stable steam valve control directly relates to improved steam turbine speed and load control and reduced system mechanical wear.

The conventional servo system is a combination of E/H Actuator, pilot valve, power cylinder and a complex system of linkages which is used to operate steam turbine control valves. The servo systems are expected to run smoothly and precisely for a long period of time but many small factors often lead to failures due to the complexity of the system. Contaminated oil is often a cause for E/H Actuator failure or it may shorten maintenance interval. The complex system of linkages along with bearings (spherical, rod-end and deva-metal) is the major point of failure in the conventional system. The multiple moving parts in the system also make it difficult to analyze and find the root cause of the failures. The cause of failures of linkages varies from high pedestal vibration or high bearing loads to small factors such as improper clearances. Another concern among Turbine OEM's is the depleting support for obsolete electrical parts of conventional E/H Actuators.

The Direct-drive Actuator system uses an integrated E/H Actuator which provides the actuation force required to operate steam turbine valve racks. This completely eliminates the use of pilot valve and power cylinder along with complex linkage system for a better, simpler and more reliable servo system. The simplicity of the system allows Turbine OEM's to redesign the servo system with minimum components and easily analyze the system. The Actuators are designed to isolate the coil from the oil thus preventing contamination or damage to the coil. The effect of various redundant parts on the availability of Actuator is also discussed.

With respect to conventional servo system:

E/H Actuator: An electrically controlled hydraulic amplifier/actuator which converts electrical signal to a proportional linear/rotary output shaft position to control the flow of steam to a prime mover.

Power Cylinder: A mechanical device which uses the hydraulic oil pressure to provide the necessary force in a linear motion required to operate the Governing valves.

Pilot Valve: A device used to supply hydraulic oil to the power cylinder depending on the movement of E/H Actuator linkages.

With respect to direct-drive Actuator:

E/H Actuator: A linear electro-hydraulic actuator that utilizes a double-acting power cylinder to provide the force and movement required to operate the steam valves. In short, all units of a conventional servo system are combined into a single and compact unit to provide precise and stable operation.

HISTORICAL DEVELOPEMENT

In past years, not only the design, efficiency and the capacity of Turbine improved, but also new kinds of E/H Actuator have been developed for use in the turbomachinery world.

The Turbine steam control systems have come a long way from Isochronous and Droop Governor which used to control the Steam Governing valve to conventional E/H Actuator, pilot valve and power cylinder servo to more robust Direct-drive Actuators. The introduction of sophisticated electronics has enabled the Actuator OEM's to combine the parts of a conventional servo to a compact unit which is simpler, precise and more reliable. The Actuators can diagnose itself for potential cause in case of a failure which helps in resolving the problem quickly and effectively but it still uses the hydraulic oil supply to provide the required stroke and force to operate the Governing valve. Owing to the requirements of the Turbine OEMs and users to move towards oil-less Turbine, improvements can be seen in the field of completely Electrical Actuators too. While the developments in Actuator is beneficial for users, it has made the users more dependent on the Actuator OEMs, as the users can't diagnose the Actuator in case of an internal failure, a spare actuator is required in most cases to take care of this issue.

CONVENTIONAL SERVO SYSTEM

The electro-hydraulic actuator convert an electrical signal to linear/rotary shaft output which can be used to drive a steam valve but the required force to move a steam valve is often very high when compared to output force of an Actuator. Small condensate turbines typically don't need the servo system shown in Figure 1 and an E/H Actuator unit alone can provide the desired motion and force. In medium to large turbines, the E/H actuator alone is insufficient; it is used to drive a pilot valve which in turn supplies oil to the power cylinder. When a control signal to increase the steam flow is received by an E/H Actuator, the Actuator shaft move in a pre-decided direction and causes movement in the pilot valve shaft. This drives the pilot valve to supply control oil to the power cylinder. The supplied oil creates a pressure difference across the piston of power cylinder which moves the GV linkage. The system of linkages forms a feedback loop which drives the pilot valve until the error between desired Actuator movement and position feedback is zero.

The conventional servo also consists of a Mechanical Trip device which is capable of shutting down the Turbine mechanically using a trip button in case of an emergency. It's a combination of piston, spring force and oil force, acts as a set of three way valves. This is used to quickly drain the control oil along with the solenoid valve.

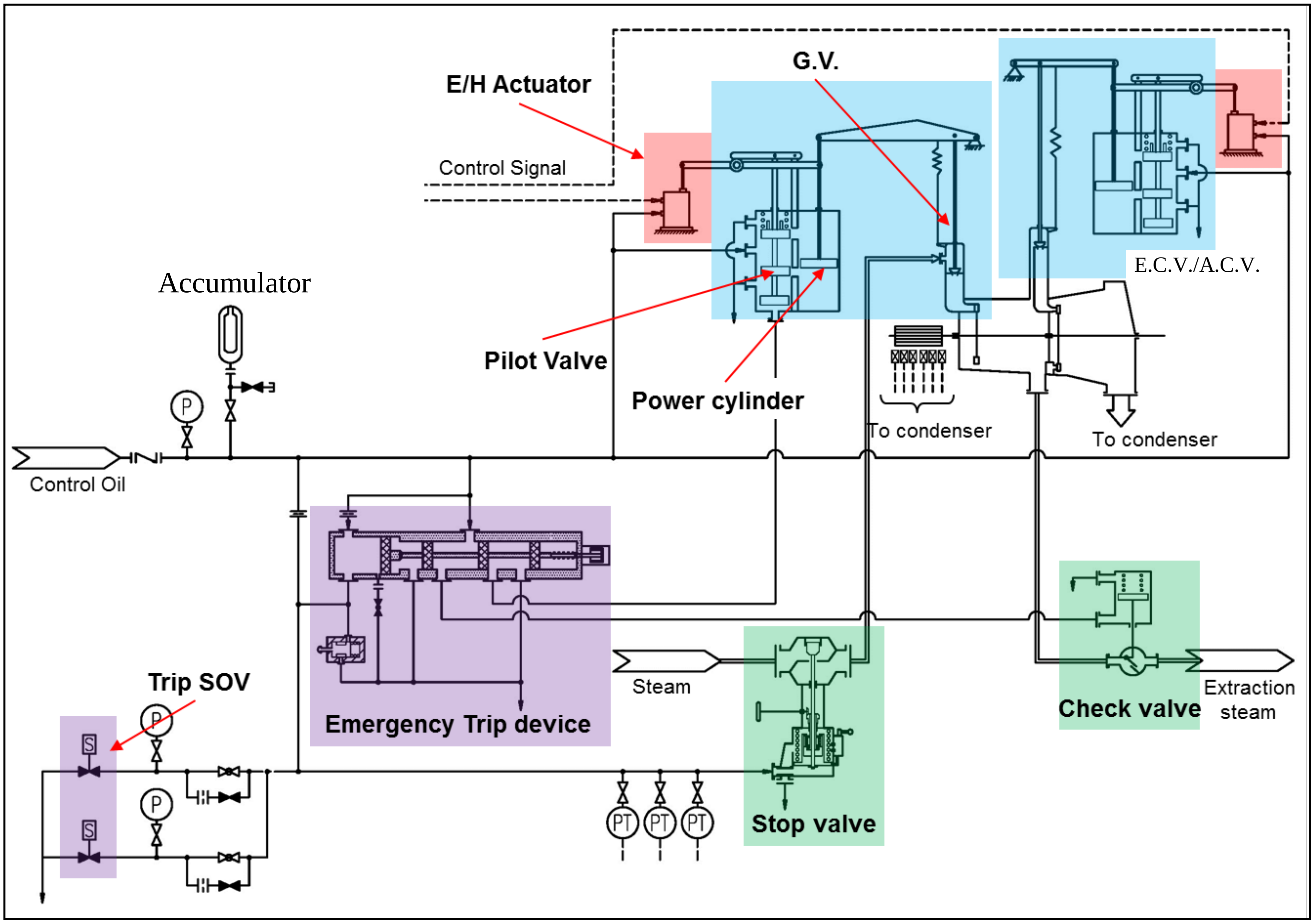


Figure 1: Conventional Servo system

PROS

The selection process of any servo system depends on many factors and customer requirements thus affecting its reliability, performance and maintenance. The conventional servo has its advantages over the direct-drive Actuator but the associated problems outweigh them all.

Stroke & G.V. Force: As the Turbine size increases, the steam flow to the turbine grows. The governing valves increases in size and so does the required force and stroke to move them. The conventional and direct-drive E/H Actuator, both have some mechanical limitations on the output force and stroke but the conventional servo system uses a power cylinder driven by an E/H Actuator (pilot valve) and modifying the linkage ratio between them enables the designers to remove any apparent limitation on force and stroke.

Input Power: This is one of those factors which won't affect the performance of a system unless there are fluctuations/ripples in the power supply. For a direct-drive Actuator, this creates a major issue for the customer and will be discussed later. For conventional servo, input power supply is not needed to drive the E/H Actuator so there are no hassles of heavy electric wiring.

Mechanical Trip Cartridge: A completely mechanical device with a trip button which can shut down the Turbine even if all the electronic equipment fails. It can be used with servo that uses control oil to provide the Actuating Force with the help of pilot valve and power cylinder. When studying the differences between servo systems, the reliability of the system depends on the Actuator as well as the Trip Cartridge.

Slew rate: One of the most important factors of a servo system is its ability to quickly shut down the steam valve in case of an emergency. The trip time of GV in case of a conventional servo will be same as the time taken by E/H Actuator to close. The conventional E/H Actuator can have trip times as low as 0.2-0.3 sec.

To understand the failures of conventional servo and study them in detail and show the difficulty faced in analyzing the system, it is important to establish a relation between Actuator, pilot valve and power cylinder's motion along with the feedback loop. Combining transfer functions with block diagrams gives a powerful method of dealing with complex systems. In the following, mathematical representation to describe inputs and outputs of model is established as shown:

A mathematical model of the servo system as shown in Figure 2 is made using block diagram to find the transfer functions of all elements including feedback loop. Based on block diagram, the transfer function is calculated as shown in Figure 3.

The bearing and other linkage related failure requires dynamic simulation to study the motion of various components of the servo system and verify the causes of the failure but lot of time is required for the same accounting for the complexity of the system as shown in the block diagram.

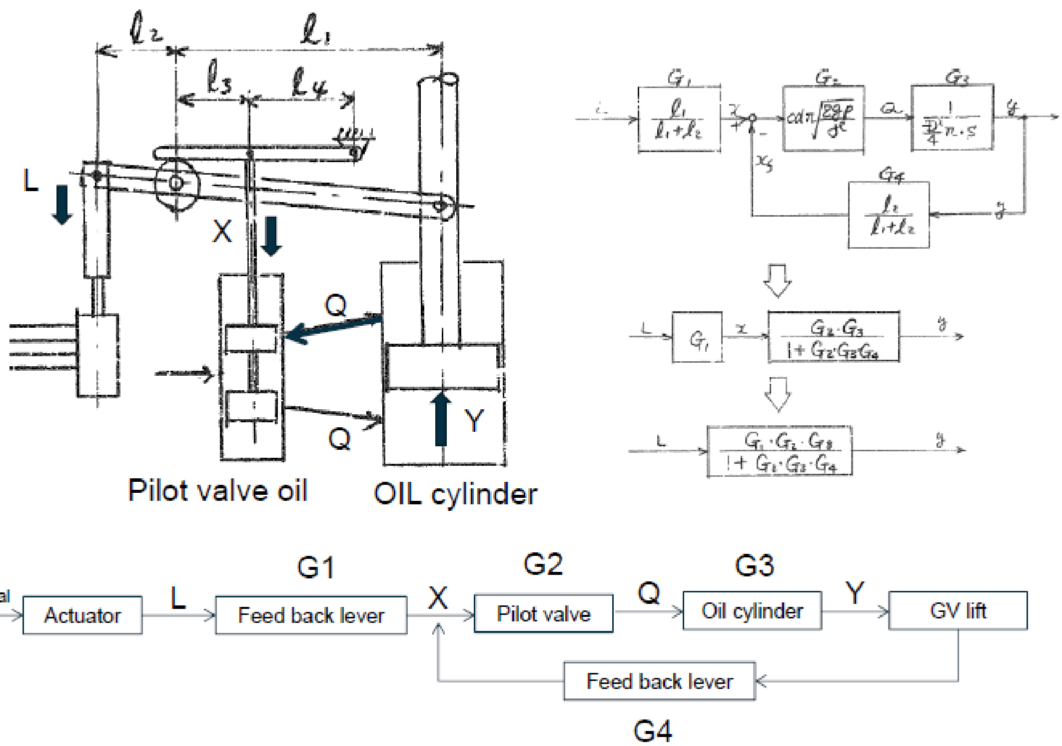


Figure 2: GV Linkage Block diagram and Transfer function

		input	output	Transfer function
Feedback lever	G1	L	X	$G1 = \frac{X}{L} = \frac{l1l4}{(l1 + l2)(l3 + l4)}$
Pilot valve	G2	X	Q	$G2 = \frac{Q}{X} = cd\pi\sqrt{\frac{2gP}{\gamma}}$
Oil cylinder	G3	Q	Y	$G3 = \frac{1}{\frac{\pi D^2}{4}S}$
Feedback lever	G4	Y	Xf	$G4 = \frac{l2}{(l1 + l2)}$

Figure 3: Transfer Function

l1/l2 = Feedback Lever Length
X = Pilot valve lift (mm)
Q = pilot valve oil flow (cm3/sec)
C = Flow factor
P = pressure (kg/cm2)
Γ = oil density
Y = Oil cylinder Lift (cm)
D = Oil Diameter (cm)
d = pilot valve diameter (cm)
Xf = pilot valve lift by feedback (mm)

CONS

Determining the reliability of a system becomes a challenging task when it involves multiple devices and moving parts. Same is the case in a conventional servo system which has multiple linkages and bearings apart from other components. The problems associated with servo range from oil contamination, hunching, calibration issues, incorrect tolerances and so on.

Linkages: To transfer the motion from E/H Actuator to the GV valve with a feedback loop, a numbers of linkages are used. As shown in Figure 4, various components of the system accounts for numbers of failure.

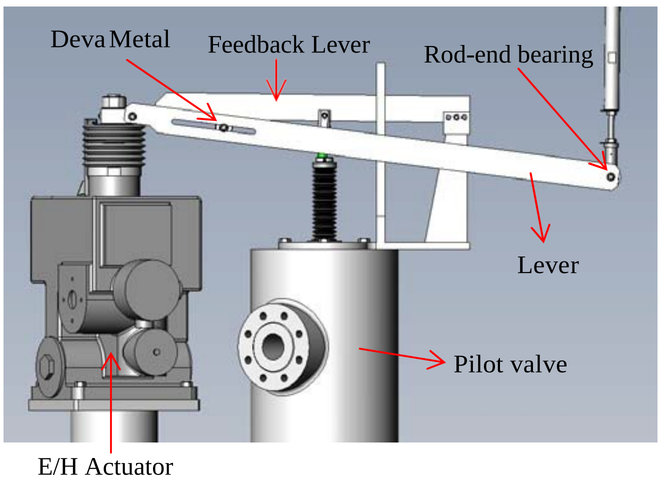


Figure 4: GV Assembly

A rod-end bearing is used to connect the GV rod to the Lever and a tight tolerance to keep the components aligned and to minimize the play. Deva Metal, a self-lubricating bearing is used between Lever and connector to provide a frictionless movement between them. Spherical bearings are also used at various parts. Bearing selection for a particular application is sometimes tricky due to availability of various types of bearings. The selection of a bearing depends on the nature of the load, radial and axial force, bearing material, operating conditions among other factors.

Case History: Bearing Failure

The screen shown in Figure 5 is from the GV Assembly of a Turbine (50 MW, 3500 rpm) driving Propylene compressor in an Ethylene plant. Rod-end bearing broke failure occurred and governing valve rod was disconnected from the Lever. This led to governing system losing control of the inlet steam forcing the Turbine to trip. The top surface of rod-end bearing was completely worn out. Wear was found out in other GV Linkage parts. The RCA was carried out and pedestal vibration data was reviewed. A missing washer on the pin at site also accounted for this failure. The failure was caused by fretting, which is a result of force and motion on a contact area.

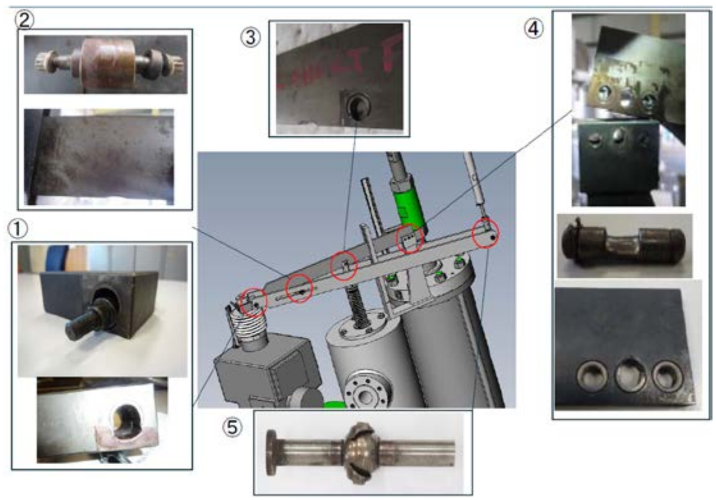


Figure 5: GV Linkage parts with wear

Case History: Lever and Deva-metal Wear

Wear of Lever at roller position and Deva-metal at support location on short feedback lever of the Governing Valve Assembly on a Turbine (55 MW, 3792 rpm) driving a process gas compressor was experienced as shown in Figure 6.
The wear on the roller was a result of Hertz stress which occurred on roller due to line contact with Lever. The wear in pilot valve at pilot-valve's connector location occurred due to fluctuations in Pilot valve and large tolerance in Deva-metal, the pin hitting the bush continuously. Continuous hitting for a long period of time caused the wear.

Figure 6: Lever and deva-metal wear

Case History: Lever Vibration

High vibration of Feedback Lever was experienced in a Turbine. The analysis indicated the source of vibration to be the spring between pilot valve rod and pilot valve connector as shown in Figure 7.

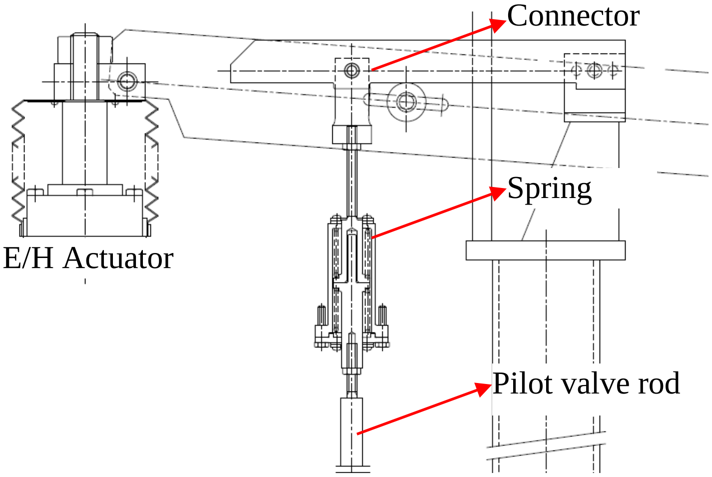


Figure 7: Vibration due to spring

A spring was installed between connector and pilot valve rod to prevent any damage to the pilot valve piston in case of the sudden movement of E/H Actuator. As the Actuator moved, the spring was compressed or stretched and the stored energy caused the mass-spring system to oscillate until the stored energy was dissipated. The problem was solved by installing a damper to absorb the energy.

E/H Actuator (Calibration Issue): The complex relation between the input and the output response of the servo system presents another problem. It is important that the Governing valve lifts precisely corresponding to an E/H Actuator input signal. The complex transfer function of linkages makes it difficult to calibrate the E/H Actuator perfectly.

E/H Actuator (Oil contamination): The conventional Actuators have its coil submerged into oil. The oil works as heat sink and also provides electrical insulation. This causes the Actuator to be very sensitive towards oil contamination leading to coil failure or sticking of power piston due to dirt, metal shavings & other contaminants in the oil.

Case History: Failure of the E/H Actuator on the Governing valve of a Turbine (30 MW, 3950 rpm) occurred after initial days of operation. The Actuator was properly commissioned before the operation started. After initial check, actuator piston was found stuck due to dirt. Further investigation revealed that the initial flushing of oil pipe was insufficient and dirt remained in the pipe. It is important to ensure that the oil and steam piping is free of dirt and any other contaminants before the operation is started.

E/H Actuator Calibration Shift: A proper calibration is difficult but important to precisely operate the Governing valves. Any problem in the E/H Actuator may cause the graph between Actuator's input signal and Actuator piston lift to shift as shown in Figure 8.

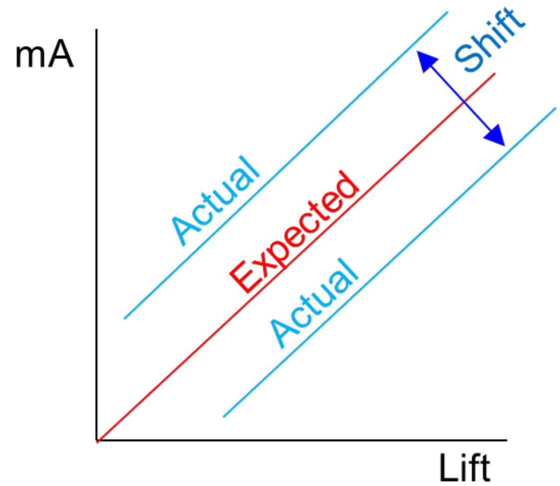


Figure 8: Actuator Calibration curve

Case History: Experienced E/H Actuator calibration shift on GV Actuator of a Turbine (14 MW, 6000 rpm) which was in operation for 3 years. The Turbine speed fluctuated from the normal speed and the efforts of the operators to control the Turbine Load and speed were in vain as Actuator Lift corresponding to the control signal had changed. Deterioration of the internal bearing of E/H Actuator caused this behavior.

Governing valve control: The precise and stable turbine speed and load control is of utmost importance. Wear/Damage in any/all components of the GV Linkage assembly will modify the transfer function and the output response will shift from expected response.
The deviation in GV valve lift corresponding to an E/H Actuator control signal can be high due to large tolerances in linkages which in turn decrease the control of operator over the Turbine speed and load.

DIRECT DRIVE ACTUATORS

A linear electro-hydraulic actuator designed to provide the linear actuation force to operate steam turbine control valves or valve racks which uses a low-pressure hydraulic oil source (typically turbine lube oil) to provide its output shaft force.

The direct-drive Actuator's superb accuracy and resolution make it ideal for steam turbine valve control and related turbine speed and load control. The Turbine OEM's current pilot valve assembly, power cylinder, E/H Actuator and feedback linkages are incorporated into a single package. Its robust design and redundant features makes it ideal for steam turbine applications. A typical setup is shown in Figure 9.

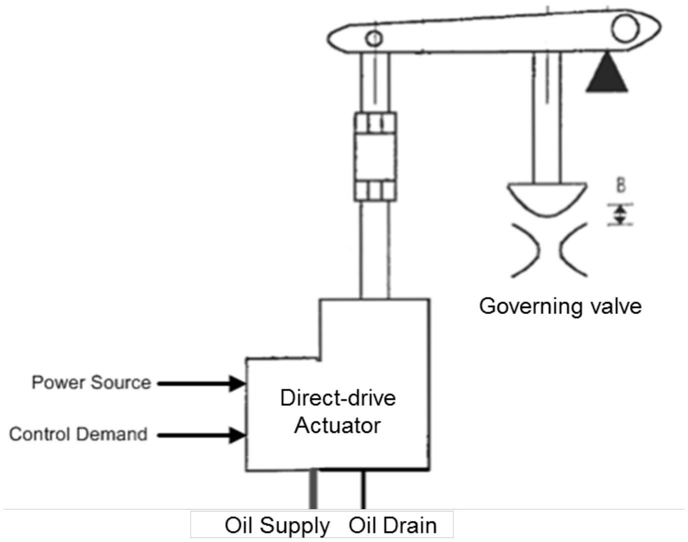


Figure 9: Direct-drive Actuator system

For Turbine retrofit applications, direct-drive actuators can be used to replace the existing servo system easily. This eliminates the difficulty of obtaining spare parts for obsolete equipment, and reduces calibration time and difficulty.

PROS

Precise and stable steam valve control directly relates to improved steam turbine speed and load control and reduced system mechanical wear. Faster slew rate (for trip) allows turbines to quickly respond to loss-of-load or emergency shutdown events. Redundant power supply, position feedback sensors and dual control signal further enhances the reliability of the servo.

Dirt Tolerance: The actuators designed for steam turbine applications uses turbine lube oil to power the hydraulic turbine control valve actuators. Steam turbine applications can be extremely challenging for hydraulic control valve actuators as dirt, metal shavings, water, and other contaminants (babbitt, ammonia, etc.) are common in such oil systems. Also due to the high temperatures at which steam turbines operate, turbine oil breakdown is common, resulting in the creation of a sludge-type substance and the varnishing of internal system components. The direct-drive Actuators are designed to operate reliably under such challenging conditions. Actuator OEM's are using corrosion-resistant materials and self-cleaning designs which allow actuator to operate in challenging applications without experiencing undesirable sticking or dragging actions.

Reliability: In such a globally competitive market where products can potentially be manufactured and shipped from overseas at a lower cost than can be manufactured from here at home, maintaining a precise level of reliability and uptime is necessary to keep costs at a manageable level.

Reliability is defined as the probability that a component (or an entire system) will perform its function for a specified period of time, when operating in its design environment. The cost for a machine breakdown is more than just the maintenance labor and materials to make the repair. The actual cost for a breakdown is a whole lot greater than maintenance costs.

Reliability can be derived from availability performance of a system. In fact, availability depends on the time between two consecutive failures and on how long it takes to restore the system which is known as Mean Time to Failure (MTTF). It doesn't tell us that the system will fail after a certain amount of time rather it depicts the Probability that the system might fail after the equipment is used for the given time. In short, it is related to Probability to Fail on Demand.

The various direct-drive Actuators available, has a MTTF of around 100-200 years while the conventional E/H Actuators has MTTF of 15-30 years. Adding the reliability of Linkage system to conventional Actuators MTTF, this value becomes lower.

Cost: One of the most important factors in the selection of any component of machinery is its cost. Each piece of machinery must perform reliably under a variety of field conditions or it is a poor choice regardless of its cost. Taking the cost of conventional servo system (includes power cylinder, pilot valve, E/H Actuator and linkages), the cost of direct-drive Actuator is equal if not lower than conventional servo.

Linkages: One of the major source of problems experienced with conventional servo system are the Linkages and bearings used. As clear from Figure 9, the linkage assembly for Direct-drive Actuators is very simple and robust. It solves the issues associated with conventional servo such as calibration, linkage/bearing wear. The mathematical model using block diagrams and corresponding transfer function is also simple for Direct-drive Actuator and analysis using dynamic simulation in case of a failure wouldn't require much time.

Maintenance: The main purpose of regular maintenance is to ensure that all equipment required for production is operating at 100% efficiency at all times. Through short inspections, cleaning, lubricating, and making minor adjustments, minor problems can be detected and corrected before they become a

major problem that can shut down a production line.
The ease with which a defect can be isolated or corrected, unexpected breakdowns can be prevented directly relates to maintainability. With the introduction of Direct-Acting Actuators, number of components such as pilot valve, power cylinder, linkages has greatly reduced thus improving the maintainability significantly.

Redundancy: Redundancy is the duplication of critical components or functions of a system with the intention of increasing reliability of the system, usually in the form of a backup or fail-safe.
There are many redundant features available on request as per Actuator design which can increase the reliability of the equipment significantly. Few of them are described as follows:

Feedback Sensor: As the design for Actuator developed over the years, the feedback system has also improved significantly to precisely control steam turbine valves. With the development of LVDT (Linear variable differential transformer) sensor to a more reliable MLDT (Magnetostrictive Linear Displacement Transducers) sensor, it has become important to have a redundant feedback system in case one of the sensors fails.

Direct-drive actuators are available with redundant LVDT while some uses MLDT position sensor. Conventional E/H Actuators didn't have any position feedback sensor and any external sensor installed on the E/H actuator had to face non-linearity issues.

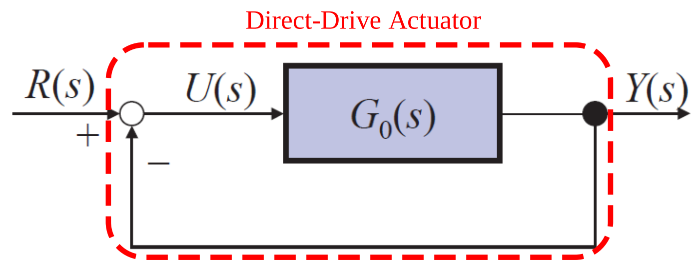
Technology	Resolution	Non-Linearity	Ruggedness
MLDT	High	Low	High
LVDT	High	Medium	High
Inductive	Medium	Medium	High
Encoder	High	Low	Low
Ultrasonic	Low	High	Medium
Potentiometer	Medium	Medium	Medium

- Higher resolution is better, and means smaller steps as the output changes.
- Lower non-linearity is better, and means the difference between a straight line and output.
- The Potentiometer is a contact-type transducer, others listed are non- contact type.

Table 1: Comparison of several position sensors

Demand Input Signal: In Dual input signal system, the Actuator have single coil but it has redundant input signals sent to the coil. Depending on the selection logic, the signal with higher value can take precedence over the other signal or the average of both signals can be used thus improving the accuracy and reliability of the system.

To better understand the difference between conventional and direct-drive Actuators and to show the simplicity in analyzing the Direct-drive systems, it is useful to establish a relation between the input and output response of the system. A mathematical model of the servo system using block diagrams and the associated transfer function is shown in Figure 10.



$$G(s) = \frac{Y(s)}{R(s)} = \frac{G_0(s)}{1 + G_0(s)}$$

Figure 10: Block Diagram and Transfer function

R(s) : Input to Actuator
Y(s) : Output (corresponds to Actuator Lift)

The complex relation between input and output signal of a conventional servo (shown in Figure 2) is simplified to the one shown in Figure 10 for direct-drive Actuators. This helps in calibrating the servo system to control the Governing valve precisely. The dynamic simulation to study the motion of links and bearings and the associated failure modes is simple.

CONS

The Direct-drive Actuators has many improvements in fields of reliability, redundancy and simplicity. It solves many problems associated with conventional servo system but it has its demerits which should be kept in mind while deciding its usage.

Atmospheric Temperature: Area close to the Turbine can reach high temperature due to heat radiating from the Turbine. This can be dangerous to electrical equipment. Incidents such as burning of electrical wire due to contact with metal body at high temperature had occurred in the past.
The Direct-drive Actuators has new and sophisticated electrical system which makes it highly vulnerable to heat when compared to a conventional servo. Care needs to be taken when deciding the location of the Actuator and temperature of the region in worst-case scenario should be estimated. Additionally, heat prevention plans should be considered to ensure the safety of the Actuator. One such remedial measure is installation of radiation reflection plates on the Actuator installed near Turbine as shown below:

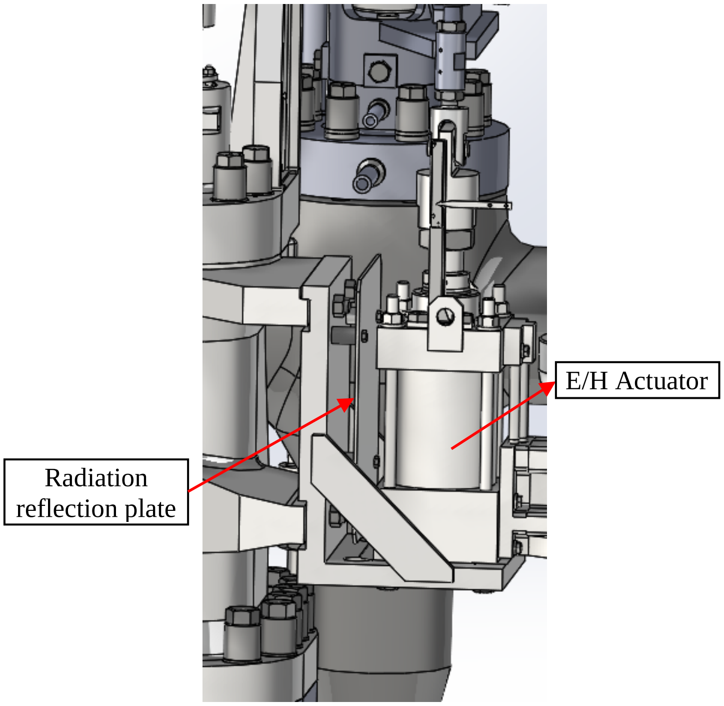


Figure 11: Actuator with radiation reflection plate

Finite Element Analysis was carried out to estimate the Temperature of the Actuator body with/without the application of radiation reflection plate. A heat source was substituted in place of the Turbine. The result of the analysis is shown in the Figure 12. At source temperature of 400 °C, the Actuator temperature can be reduced by approx. 50°C if radiation reflection plate is used. It can be seen that the radiation reflection plate is an effective measure which can protect the electrical equipment by significantly reducing the heat radiation reaching the Actuator.

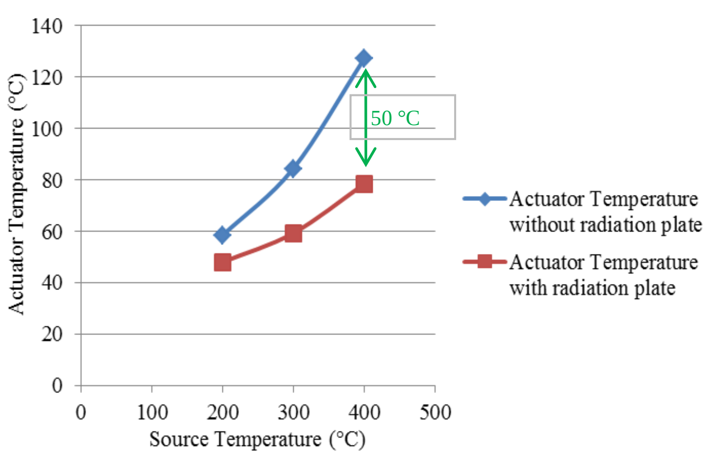


Figure 12: Effect of radiation plate on Actuator Temperature

Other measures include insulating the Actuator and/or changing the Actuator location.

Compatibility of each train: For a conventional servo system, turbine OEM's used to optimize the size of pilot system and power cylinder for each turbine and E/H Actuator model is kept same for all the Turbines in a project.

Unlike conventional servo, the direct-drive Actuators have to be selected individually for each turbine on the basis of oil cylinder diameter and actuator stroke. After selection, the Actuator model in a project can be optimized to reduce the number of different models. Different models of an Actuator in a project mean that the customer has to spend a lot of money on spare parts for each model and storage will be needed for them.

Actuator Stroke: After the introduction of Direct-drive Actuators, stroke is one of the limitations which limit these Actuators application across the full range of steam Turbines. Reducing the required Actuator stroke means that the Lever connecting the GV rod and Actuator shaft needs to be shortened but this would move the Actuator close to the Turbine where the Temperature can be higher than the Actuator's operating limit.

This is also creates a problem in revamp project when power cylinder can't be replaced by these Actuators due to stroke limit and changing the Actuator location would mean a new support is needed at another location.

Power Supply: This is one the major disadvantages with Direct-drives Actuators. A DC input supply is not preferred by the customer as the cable might become very thick to compensate for the loss of power over long distance (Power supply room to Actuator). If the required power supply is (100V, 10 A), the required cable will be around 100-300 mm to supply power over long distances. So the power supply can't be stationed far away from the Turbine due to Voltage drop across the cable length. The alternate is to place the power supply box near the Turbine due to cable size limitations but hazardous protection should be applied. The cost will be 10-fold larger when compared to a power supply box placed in control room with no hazardous protection.

CONCLUSIONS

In this Lecture, we have outlined the merits and problems associated with conventional servo system and direct-servo actuators particularly Linkage failures and difficulty in analyzing them for conventional servo.

The Direct-drive Actuators has improvements in various fields over conventional servo which has led to a more reliable and efficient system requiring minimum maintenance. The ability of these actuators to precisely control the governing valves leads to a stable operation, better load control and reduced system mechanical wear. The redundant features make it ideal for critical steam turbine applications, where turbine up-time and availability are essential.

As of any device, there are issues and limitations associated with direct servo such as high temperature, DC power supply, compatibility which needs to be thoroughly discussed.

Another issue with the direct-drive Actuators is the lack of long term field experience. The pros and cons of both types of servo should be studied in detail and informed to customers so that the customers are comfortable using it now more than ever.

ABBREVIATIONS

OEM	:	Original Equipment Manufacturer
E/H	:	Electro-Hydraulic
GV	:	Governing valve
ECV	:	Extraction control valve
ACV	:	Admission control valve
SOV	:	Solenoid valve
RCA	:	Root cause analysis
MTTF	:	Mean Time to Failure
LVDT	:	Linear Variable Differential Transducer
MLDT	:	Magnetostrictive Linear Displacement Transducer
DC	:	Direct Current

ACKNOWLEDGEMENTS

The authors wish to thank all involved colleagues from MCO and Vasanth M Bhat for the technical assistance and the precious feedback.