Modelling and Strength Analysis of Diaphragm Accumulator

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Abstract—Diaphragm accumulators use the compressibility of a gas (nitrogen) in storing hydraulic energy. This nitrogen gas is required because fluids are practically incompressible and cannot store energy by themselves. The diaphragm is used to separate the gas and the fluid sides of the accumulator. These are successfully applied to both industrial and mobile applications to store energy, maintaining pressure, leakage compensation and vehicle hydraulic systems.

Keywords—Accumulator, Diaphragm, Pressure, Analysis, Structural

I. INTRODUCTION

All the energetic systems, like mechanical, electric, hydraulic or some combination of these systems can be expressed in terms of effort and flow. The power transferred from one energetic element to the other energetic element is always a product of the two elements like force and velocity, voltage and current, pressure and volumetric flow rate. The energy is the time integral of power, so energy transfer can be simply measured as the integral of this product over time. The relationship between flow and effort is a reactionary one, governed by the properties of each system element. For potential energy storage elements, this relationship is an algebraic function between the integral of flow and effort, force and displacement for springs, charge and voltage for capacitors, volume and pressure change for hydraulic accumulators. Hydraulic accumulators have the ability to store excess energy and release it whenever needed. These are useful tools for improving hydraulic efficiency. Industrial accumulators are classified as hydro and pneumatic. This type of accumulator applies a force to the fluid by using compressed gas. The two common types of accumulators are the rubber bladder type and the piston type accumulator. The below presented is the rubber bladder type accumulator. Just as spring constants dictate the force displacement relationship of springs.

The bulk modulus (the inverse of compressibility) dictates the relationship between pressure and volume change in hydraulic accumulators. Since hydraulic fluid itself having very high bulk modulus, miniscule changes in the volume of a closed hydraulic system result in large swings in pressure. Pump-motor noise can cause unsafe pressure fluctuations in this way if unaccounted. Commercial hydraulic accumulators resolve this by providing temporary storage for this oscillating flow in a device with a much more favorable pressure-volume change relationship. Because they contain bags of compressible gas, these accumulators have a much lower efficient bulk modulus and thus respond to small changes in volume with even smaller changes in pressure.

II. LITERATURE SURVEY

Zainol (1990) have reported that the major problem of back pressure vessel was the loss of steam of about 27 to 50% to the atmosphere. This is due to its design and size which are not specific for accumulating and controlling the steam distribution to the sterilizers and factory heating. Its function is more as a temporarily steam storage vessel for maintaining the turbine performance. The practice of venting off steam from the back pressure vessel to atmosphere over a certain minimum time is inevitable when the accumulation of steam in the back pressure vessel exceeds the relief valve set point (around 45 psi). Consequently, there is a deficit in steam supply to the sterilizers, resulting in fresh fruit bunches not being fully sterilized.

Mustafa (1994) have identified three major types of disturbances that lead to the severe steam fluctuations in steam supply and demand. The most critical type is random steam fluctuations in boiler, steam turbine, back pressure and sterilizers resulting in steam venting or time delay. The next disturbance is variation of boiler pressure due to inconsistent fuel quality which affects all units downstream and the last type is random steam injection in palm oil stream such as digester to maintain temperature and flow.
Ng (1994) have reported that under the best sterilization condition with proper sequencing of the three sterilizers, there was an increase in steam input to the steam system, but the steam loss through the boiler and the back pressure vessel to the atmosphere has also increased. The back pressure vessel accounted for about 65% of the total steam loss to the atmosphere. This high steam loss is mainly due to its size limitation to control and cope with the steam demand at the sterilizers because of the enormous difference in volume between the back pressure vessel and the sterilizers.

Sivasothy (1997 & 1998) have identified that one of the problems experienced with boiler control systems was the slow dynamic response of the steam pressure to changes in fuel firing rate. This constraint tends to restrict the ability of simple feedback systems to respond to sudden large fluctuations in steam demand. As in the above case, several experimental studies were performed by implementing a feed forward control system where fuel flow rate to the boilers could be increased before the start of sterilization cycles in anticipation of an increase in steam demand. The problem of slow dynamic response of steam pressure is significantly eliminated using the new control system.

A practical and integrated approach to the steam management for palm oil mills known as the mill wide intelligent steam management control system was proposed by Lim et al., (1997). This control system comprises various critical process control sub-systems such as sterilizer control system, back pressure receiver control system, combustion control system and boiler drum level and blow control systems to maintain a balance between steam demand and supply. The mill wide intelligent steam management control system for palm oil mills has reported both encouraging and beneficial results. From the literature reviewed above, it can be concluded that one of the most critical problems faced by palm oil mill industry is the severe and dominating periodic fluctuations of steam supply and demand.

Therefore, a proper energy management is needed to be implemented in the steam system for providing solution to the problem.

The first steam accumulator was installed at the beginning of this for balancing the waste steam from winding machines (Goldstern, 1970). The principle of steam accumulation used in the system was limited for the pressure range of up to 2 bars and automatic regulation was not yet incorporated. Ruths (1913) then applied the same basic principle of steam storage to higher pressure systems and automatic operations in 1920’s.

In connection with the new development, the application of pressure drop accumulator to balance the boiler load by inserting an overflow or surplus regulator between the boiler and the accumulator has been successfully carried out. This was followed by similar developments of the feed water storage system or constant pressure accumulator for medium fluctuations, especially the displacement type in 1960 (Godall, 1980). For power station applications, special storage systems for turbines were developed with pressures up to 150 bars in 1938 (Lyle, 1947). At present, new systems are being developed for nuclear power and for solar and other unconventional sources of energy, aiming at steam storage volumes of several thousand cubic meters per unit.

III. WORKING PRINCIPLE

The rubber bladder is compressed when the fluid under pressure is supplied to the hydraulic accumulators and the oil and gas pressure increases. Conversely, when accumulator supply oil to the hydraulic system, the oil pressure drops and the rubber bladder expands.

Fig. i. Schematic Diagram of Diaphragm Accumulator

Whenever additional oil is required by the system, it is supplied by the accumulator even as the pressure in the system drops by a noticeable amount. The bladder is pre-charged with nitrogen to a pressure given by the manufacturer according to the operating conditions. When the system pressure exceeds the pre-charged gas pressure, the oil valve opens and hydraulic fluid enters into the accumulator.
A hydraulic accumulator is a pressure storage reservoir in which a non-compressible hydraulic fluid is held under pressure by an external source. The external source can be a spring, raised weight, or compressed gas.

A hydraulic accumulator enables a hydraulic system to cope with extreme demand using a less powerful pump, store power for intermittent duty cycles, provide emergency or standby power, respond more quickly to a temporary demand, smooth out pulsations and compensate for some leakage loss.

A hydraulic accumulator is a type of energy storage device. Hydraulics has a wealth of experience in supplying hydraulic accumulators and other hydraulic components, backed up by extensive product and hydraulic systems knowledge so we can be confident that our hydraulic equipment is really suitable for purpose.

IV. CONSTRUCTION OF DIAPHRAGM ACCUMULATOR

Hydraulic diaphragm accumulators use the compressibility of a gas in retaining the hydraulic energy. The compressed gas has been required because fluids are practically incompressible and they cannot retain energy by themselves. The diaphragm is used to separate the gas and the fluid sides of the accumulator.

The diaphragm accumulator works by taking in fluid from the hydraulic circuit when the pressure increases and compresses the gas. It gives this energy to the circuit as the pressure decreases by the expansion of the gas. A poppet valve is incorporated in the diaphragm to prevent its extrusion through the fluid port.

The two types of diaphragm accumulators are welded type (non-repairable) and threaded type (repairable). These have been successfully used in commercial applications for maintaining pressure, energy storage, leakage compensation and vehicle hydraulic systems (for example vehicle brake and suspension).

Both types of diaphragm accumulators have the same type of built. The main difference is in the shell, i.e. The welded version uses a shell similar to electron-beam welded, and it cannot be repaired. The threaded type accumulator has a shell which consists of two halves (top and bottom) that are held together by a threaded type locking.

A. Diaphragm Materials

The following type of elastomers are used for manufacturing diaphragm. Standard Nitrile, Low Temperature Nitrile, Epichlorohydrin, Butyl, Fluor elastomers. In the application of certain aggressive or corrosive fluids, or in a corrosive environment, it offers protective coatings and corrosive resistant materials (i.e. stainless steel) for the accumulator parts which comes in contact with the fluid, or exposed to the hostile environment. Diaphragm accumulators are designed in such a way that it can be mounted in any position. In systems where contamination is a problem, it is recommended to use a vertical mount with fluid port oriented downward. Hydraulic diaphragm accumulators are designed to be screwed directly onto the system.

B. Applications

Diaphragm actuators are used in following applications. Some of them are Agricultural Machinery & Equipment, Cranes vehicles, Forestry Equipment, die casting machinery, Energy power plants, Steel industry, Plastic, Machine tools, Oil & gas / offshore and Suspension system for vehicles.

V. RESULTS AND DISCUSSIONS

A. Static Structural Analysis

Structural analysis is probably the most widely used application of the finite element method. The term structural (or structure) implies not only to civil engineering structures such as bridges and buildings, but also for naval and aeronautical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical structures and components such as pistons, machine parts, and tools.

A static analysis determines the effects of steady loading conditions on a structure, but ignores inertia and damping effects, which are caused by time-varying loads. A static analysis includes steady inertia loads (such as rotational velocity and gravity), and time-varying loads that can be approximated as static equivalent loads (such as the static equivalent wind and seismic loads commonly defined in many buildings). Static analysis computes the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce noticeable inertia and damping effects. Steady loading and response conditions are assumed as the loads and the structure’s response are assumed to change slowly with respect to time. Some of the loading that can be applied in a static analysis are:

Modal Analysis: Modal analysis is used for determining the modal characteristics (like natural frequencies and mode shapes) of a structural components while it is being designed. It can also be used as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis.
Fig. i. Mode shape at first natural Frequency

Fig. ii. Mode shape at third natural Frequency

Fig. iii. Mode shape at fourth natural Frequency

Fig. iv. Mode shape at fifth natural Frequency

Fig. v. Mode shape at seventh natural Frequency

Fig. vi. Mode shape at eighth natural Frequency

Fig. vii. Mode shape at ninth natural Frequency
Gravitational Analysis: When the accumulator is subjected to the gravitational loading. The behaviour of the accumulator is shown below.

![Displacement plot of the accumulator under gravitational loading.](image1)

![Vonmises stress plot for the accumulator under gravitational loading.](image2)

Internal Pressure Loading: When the accumulator is subjected to the internal pressure. The behaviour of the accumulator is shown below.

![Displacement plot of accumulator under internal pressure of 2MPa](image3)

![Vonmises stress plot for accumulator under internal pressure of 2MPa](image4)
Fig. xiii. Accumulator under internal pressure of 5MPa

Fig. xiv. Vonmises stress plot for accumulator under internal pressure of 5MPa

Fig. xvi. Displacement plot of accumulator under internal pressure of 10MPa

Fig. xvii. Vonmises stress plot for accumulator under internal pressure of 10MPa
VI. CONCLUSION

Steel Material yield strength has 250MPa The Stress achieved is 162MPa The Structure is safe with working load on 10Mpa and First Natural frequency of the structure is 78Hz which is excitation criteria of 25Hz Lower installed system costs, accumulator assisted hydraulics can reduce the size of the pump and electric motor which results in a smaller amount of oil used, a smaller reservoir and reduced equipment. Less leakages and maintenance costs, the ability to reduce system shocks will increase the component life, lesser leakage from pipe joints and minimize hydraulic system maintenance costs. Improved performance, low inertia bladder accumulators can provide instantaneous response time to achieve peak flow requirements. They can also help to achieve constant pressure in system using variable displacement pumps for better productivity and quality. Reducing noise levels, reduced pump and motor size couple with system shock absorption, overall machine sound levels and result in higher operator productivity. Flexible design approaches a vast range of accumulator types and sizes. Including accessory items, it provides a versatile and easy to apply design approach.

REFERENCES

[7] Hydraulic Accumulator (Prembaboo)