Introduction

Springs and buffers cannot match the performance of linear decelerators (the correct name for industrial shock absorbers). A decelerator acts just like your hand does when you catch a ball. The linear deceleration characteristics match the speed and mass of the moving object and brings it smoothly to rest. The energy is released harmlessly, mostly as heat.

Springs and buffers act differently. They store energy rather than dissipate. So although they stop the moving object, it bounces back. Dashpots when misused are not much better. Their peak resistance comes at the beginning of the stroke, and then falls away quickly. This causes greater resisting forces than necessary.

Kinetic energy increases with the square of the speed and as operating speeds rise under continual demand for higher productivity, shock damage to equipment becomes an increasingly serious problem, resulting in costly downtime and loss of production.

An increase in production rates is therefore only possible by dissipating kinetic energy and thereby eliminating the destructive deceleration forces.

Kinetic energy can be dissipated by using friction, as in a car whose energy is changed into heat energy by friction at its brake surfaces.

It can also be dissipated by mechanically deforming another object such as a spring or rubber bumper. In practice such devices are unsatisfactory as they only store energy and bounce it back into the system causing fatigue and premature structural failure.

Another device which is often misapplied in energy dissipation is the dashpot or cylinder cushion. The true function of a dashpot is to provide a constant velocity to a moving part and if used to absorb energy it gives rise to high force peaks at the beginning of its stroke.

Most common energy absorbing devices contribute to shock rather than reduce it because they do not dissipate kinetic energy at a uniform rate.

Due to this non-linear deceleration the object being stopped is subjected to destructively high force levels (shock) either at the beginning or the end of the deceleration stroke.

The ideal solution for this problem is achieved when the energy of the object is linearly absorbed.

That means the required deceleration force is evenly distributed over the entire stroke length to give constant or linear deceleration.

Shock absorbers stop moving objects safely and effectively, without shock, by achieving controlled linear deceleration.

Principles of operation

Virtually all manufacturing processes involve movement of some kind. In production machinery this can involve linear transfers, rotary index motions, fast feeds, etc. At some point these motions change direction or come to a stop.

Any moving object possesses kinetic energy as a result of its motion and if the object changes direction or is brought to rest, the dissipation of the kinetic energy can result in destructive shock forces within the structural and operating members of the machine or equipment.
Security

Industrial shock absorbers and automobile braking system have two crucial functional similarities.
1. Both should bring a moving mass quickly and safely to rest without any recoil or 'bounce back'.
2. Both must never suddenly fail without warning.
If an automobile braking system ever failed suddenly without warning it would almost certainly result in a serious vehicle accident. If an industrial shock absorber failed suddenly it could cause serious damage to the machine it was installed on. In many cases this could result in a complete production line being stopped with resultant enormous downtime costs.

Some shock absorber manufacturers use tube stock to make their absorber bodies and inner pressure tube. These tubes are then sealed by an end plug held in with retaining rings or circlips and seated by elastomer 'O' rings or similar. Under overload conditions the circlip or seals can fail or be extruded causing sudden and catastrophic failure of the shock absorber.

In contrast RS offer ACE shock absorber bodies and inner pressure chambers which are fully machined from solid high tensile alloy steel. This gives a completely closed end one piece pressure chamber with no seals or circlips being necessary. The advantage of this design concept is that the ACE shock absorber is able to withstand much higher internal pressures or overload without damage giving a very high safety margin. The chance of a sudden failure due to over- load etc. is effectively ruled out.

Linear decelerators (shock absorbers) are virtually maintenance free, self contained hydraulic devices with a series of adjustable orifices.

On impact the piston rod is pushed into the shock absorber. The hydraulic fluid situated in front of the piston (5) is initially displaced through all the orifices (6) resulting in smooth pick up of the moving load. As the piston moves down its stroke the orifices are progressively closed off gradually slowing the moving object down to rest.

Due to the specific spacing of the orifices the pressure generated in front of the piston remains constant throughout the entire stroke as the velocity is reduced to zero. Consequently the resisting force remains constant and uniform or linear deceleration is achieved.

An external adjusting ring (3) is used to regulate the orifice sizes enabling perfect deceleration to be achieved with varying loads and speeds and propelling forces. The displaced hydraulic fluid is stored in an internal accumulator containing closed cell elastomer foam (8). A non-return valve (4) built into the piston head and the return spring (1) enable a quick reset ready for the next cycle.

ACE linear decelerators (shock absorbers) bring a moving load smoothly to rest with the lowest possible force in the shortest possible time. The massively constructed outer body, large area bearing surfaces and minimum seals coupled with painstaking quality control assure a long and trouble free working life.

1. Hydraulic dashpot (high stopping force at start of the stroke). With only one metering orifice the moving load is abruptly slowed down at the start of the stroke. The braking force rises to a very high peak at the start of the stroke (giving high shock loads) and then falls away rapidly.

The majority of the energy is absorbed at the start of the stroke.
2. Springs and rubber buffers (high stopping force at end of stroke). These have an increasing force characteristic, becoming a solid stop at full compression. Also they store energy rather than dissipating it, causing the load to rebound back again.

3. Air buffers, pneumatic cylinder cushions (high stopping force at end of stroke). Due to the compressibility of air these have a sharply rising force characteristic towards the end of the stroke. The majority of the energy is absorbed near the end of the stroke.

4. RS industrial shock absorbers (uniform stopping force through the entire stroke). The moving load is smoothly and gently brought to rest by a constant resisting force throughout the entire shock absorber stroke. The load is decelerated with the lowest possible force in the shortest possible time eliminating damaging force peaks and shock damage to machines and equipment. This is a linear deceleration force stroke curve and is the curve provided by RS shock absorbers.

Both devices are stopping the same mass at the same impact velocity and in the same stroke length. Therefore they are both absorbing the same energy.

Result: The shock absorber stops a moving load of the same kinetic energy in a third of the time of a dashpot or cylinder cushion. As a result cycle times are reduced giving higher production rates.

Adjustable shock absorbers

The adjustable shock absorber offers flexibility in application design and selection procedure. With the widest range of effective weight, one model can cover many applications. By simply 'tuning in' another orifice when an effective weight change is necessary, the total orifice area changes, providing the required constant internal pressure.

Self-compensating shock absorbers

In cases where non-adjustability is beneficial but the features of an adjustable shock absorber are required, self-compensating models meet both needs. With a wide range of effective weight, a self-compensating shock absorber will provide acceptable deceleration despite changing energy conditions.

The orifice profile, designed by a computer that constantly arranges the size and location of each orifice while inputting changing effective weights, neutralises the effect of changing fluid coefficients, weight, velocity, temperature and fluid compressibility.
A linear decelerator by definition decelerates a moving weight at a linear or constant rate of deceleration. The adjustable shock absorber is able to provide linear deceleration when operated within its energy capacity and effective weight range by dialling in the required orifice area. The resulting force-stroke curve (figure 7) shows the optimum (lowest) stopping force.

Figure 7 shows the force-stroke curve of a self-compensating shock absorber stopping a weight at the low end of its effective weight range. Note how the reaction forces are no longer constant but are still acceptable. The curve is skewed slightly higher at the beginning of the stroke and dips lower at the end.

A force-stroke curve of the same self-compensating shock absorber, but at the high end of its effective weight range, is shown in figure 9. The energy curve is now skewed upward at the end of stroke and still yields acceptable deceleration.

Figure 8 shows the force-stroke curve of a self-compensating shock absorber stopping a weight at the low end of its effective weight range. Note how the reaction forces are no longer constant but are still acceptable. The curve is skewed slightly higher at the beginning of the stroke and dips lower at the end.

Effective weight

Effective weight is an important factor in selecting shock absorbers. A shock absorber ‘sees’ the impact of an object in terms of weight and velocity only; it does not ‘see’ any propelling force. The effective weight can be thought of as the weight that the shock absorber ‘sees’ on impact. Effective weight includes the effect of the propelling force on the performance of the shock absorber.

Failing to consider the effective weight may result in improper selection and poor performance of a shock absorber. Under extreme conditions an effective weight that is too low for the shock absorber may result in high forces at the start of stroke (high on-set force). Conversely an effective weight that is too high for the shock absorber may cause high forces at the end of stroke (high set-down force).

Consider the following examples:

1. A mass of 3kg travelling at 6 metres per second has 54 Newton meters of kinetic energy (figure 11). On this basis alone a Model A 1/2 x 1 shock absorber would be selected. However, because there is no propelling force on the application the calculated effective weight is 3kg. This is below the minimum effective weight range of 5kg min to 450kg max. If this model were used the result would be a high on-set force at the beginning of the stroke (figure 12). The solution in this case would be to use a specially orificed shock absorber to handle the low weight/high speed combination or alternatively to use the self-compensating model MC 1201 M-0.

2. A mass of 50kg has an impact velocity of 0.3 metres per second and is driven by a propelling force of 2000 Newtons (figure 13). Total impact energy is 53Nm and again a model A 1/2 x 1 would be selected based just on the energy to be absorbed. However, the effective weight calculates to 1177kg which is well above the maximum for a standard model A 1/2 x 1. If this shock absorber was used, high set-down forces at the end of stroke would result (figure 14). The solution in this case is to use a model LVA 1/2 x 1 which is designed to work in low velocity, high effective weight applications such as this.
Further examples of the calculation of effective weights follow:

**Formulae and calculations**

Ace shock absorbers provide linear deceleration and are therefore superior to other kinds of damping element. It is easy to calculate around 90% of applications knowing only the following 4 parameters:

1. Mass to be decelerated (weight) \( m \) (kg)
2. Impact velocity \( v_0 \) (m/s)
3. Propelling force \( F \) (N)
4. Cycles per hour \( C \) (/hr)

**Key to symbols used**

- \( W_1 \) : Kinetic energy per cycle (Nm)
- \( W_2 \) : Propelling force energy per cycle (Nm)
- \( W_3 \) : Total energy per cycle \((W_1 + W_2)\) (Nm)
- \( W_4 \) : Total energy per hour \((W_3 \times C)\) (Nm/hr)
- \( m_e \) : Effective weight (kg)
- \( m \) : Mass to be decelerated (kg)
- \( \omega \) : Angular velocity \(\left(\omega = 2\pi \theta / 360 \times \right)\) (rad/s)
- \( F \) : Propelling force (N)
- \( C \) : Cycles per hour (/hr)
- \( P \) : Motor power (kW)
- \( ST \) : Stall torque factor (normally 2.5) 1 to 2.5
- \( M \) : Propelling torque (Nm)
- \( I \) : Moment of inertia (kgm²)
- \( g \) : Acceleration due to gravity = 9.81 (m/s²)
- \( h \) : Drop height excl. shock absorber stroke (m)
- \( s \) : Shock absorber stroke (m)
- \( L/R/r \) : Radius (m)
- \( Q \) : Reaction force (N)
- \( \mu \) : Coefficient of friction
- \( t \) : Deceleration time (sec)
- \( 'g's \) : Deceleration rate (g/s)
- \( \alpha \) : Side load angle (°)
- \( \beta \) : Angle of incline (°)
- \( \theta \) : Index degrees (°)
- \( X \) : Index time (sec)

\(*v\) or \( v_0 \) is the final impact velocity of the mass. With accelerating motion the final impact velocity can be 1.5 to 2 times higher than the average velocity. Please take this into account when calculating the kinetic energy. In the following examples the choice of shock absorber made from the capacity chart is based upon the values of \((W_3), (W_4), (m_e)\) and the desired shock absorber stroke(s).
1. Mass without propelling force

**Formulae**

\[ W_1 = m \cdot v_0^2 \cdot 0.5 \]

**Example 1**

\[ \begin{align*}
W_1 &= 100 \cdot 1.5^2 \cdot 0.5 = 113\text{Nm} \\
m &= 100\text{kg} \\
v_0 &= 1.5\text{m/s} \\
C &= 500\text{h} \\
s &= 0.05\text{m (chosen)} \\
me &= m = 100\text{kg}
\end{align*} \]

2. Mass with propelling force

**Formulae**

\[ W_1 = m \cdot v_0^2 \cdot 0.5 \]

**Example 2**

\[ \begin{align*}
W_1 &= 36 \cdot 1.8^2 \cdot 0.5 = 41\text{Nm} \\
m &= 36\text{kg} \\
v_0 &= 1.5\text{m/s} \\
F &= 400\text{N} \\
C &= 1000\text{hr} \\
m &= 2 \cdot 1.5^2 = 45\text{kg}
\end{align*} \]

3. Mass with motor drive

**Formulae**

\[ W_1 = m \cdot v_0^2 \cdot 0.5 \]

**Example 3**

\[ \begin{align*}
W_1 &= 800 \cdot 1.2^2 \cdot 0.5 = 576\text{Nm} \\
m &= 800\text{kg} \\
v_0 &= 1.2\text{m/s} \\
ST &= 2.5 \\
P &= 4kW \\
me &= 2 \cdot 1426 \cdot 1.2^2 = 1981\text{kg}
\end{align*} \]

4. Mass on driven rollers

**Formulae**

\[ W_1 = m \cdot v_0^2 \cdot 0.5 \]

**Example 4**

\[ \begin{align*}
W_1 &= 250 \cdot 0.5 \cdot 9.81 = 147\text{Nm} \\
m &= 250\text{kg} \\
v_0 &= 1\text{m/s} \\
M &= 50\text{Nm} \\
L &= 0.8\text{m} \\
C &= 1500\text{hr} \\
s &= 0.0125\text{m (chosen)} \\
me &= 2 \cdot 162 = 33\text{kg}
\end{align*} \]

5. Swinging mass with propelling force

**Formulae**

\[ W_1 = m \cdot v_0^2 \cdot 0.5 \]

**Example 5**

\[ \begin{align*}
W_1 &= 20 \cdot 1^2 \cdot 0.5 = 10\text{Nm} \\
m &= 20\text{kg} \\
v_0 &= 1\text{m/s} \\
R &= 50\text{Nm} \\
L &= 0.8\text{m} \\
C &= 1500\text{hr} \\
s &= 0.0125\text{m (chosen)} \\
me &= 2 \cdot 162 = 33\text{kg}
\end{align*} \]

6. Free falling mass

**Formulae**

\[ W_1 = m \cdot g \cdot h \]

**Example 6**

\[ \begin{align*}
W_1 &= 30 \cdot 0.5 \cdot 9.81 = 147\text{Nm} \\
m &= 30\text{kg} \\
h &= 0.5\text{m} \\
C &= 400\text{hr} \\
s &= 0.05\text{m (chosen)} \\
me &= 2 \cdot 162 = 33\text{kg}
\end{align*} \]
6.1 Mass rolling/sliding down incline

**For all equations use:**
- **W1 = mg \cdot h = m \cdot v_D^2 \cdot 0.5**
- **W2 = mg \cdot \sin \beta \cdot s**
- **W3 = W1 + W2**
- **W4 = W3 \cdot C**
- **v_D = \sqrt{2 \cdot g \cdot h / 2 \cdot W3}**
- **m_e = v_D^2 / me**

**Example:**

- **W1 = m \cdot g \cdot h = m \cdot v_D^2 \cdot 0.5**
- **W2 = m \cdot g \cdot \sin \beta \cdot s**
- **W3 = W1 + W2**
- **W4 = W3 \cdot C**

**Notes:**
- a with propelling force up incline
- **W2 = (F - m \cdot g \cdot \sin \beta) \cdot s**
- b with propelling force down incline
- **W2 = (F + m \cdot g \cdot \sin \beta) \cdot s**

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7. Rotary index table with propelling torque

**Formulae**

- **W1 = m \cdot v^2 \cdot 0.25 = 0.5 \cdot 1 \cdot m^2**
- **W2 = \frac{M \cdot s}{R}**
- **W3 = W1 + W2**
- **W4 = W3 \cdot C**
- **v_D = \sqrt{v \cdot R} = m \cdot R**
- **m_e = \frac{2 \cdot W3}{v_D^2}**

**Example 7**

- **W1 = 1000 \cdot 1.12 \cdot 0.25 = 303Nm**
- **m = 1000kg**
- **v = 1.1m/s**
- **W2 = 303 + 63 = 366Nm**
- **s = 0.05m (chosen)**
- **W3 = 303 + 63 = 366Nm**
- **W4 = 366 \cdot 100 = 36600Nm/hr**
- **C = 100/hr**

**Note:** Formulae given are only correct for circular table with uniform weight distribution.

8. Swinging arm with propelling torque

**Formulae**

- **W1 = m \cdot v^2 \cdot 0.18 = 0.15 \cdot 1 \cdot m^2**
- **W2 = \frac{M \cdot s}{R}**
- **W3 = W1 + W2**
- **W4 = W3 \cdot C**
- **v_D = \sqrt{v \cdot R} = m \cdot R**
- **m_e = \frac{2 \cdot W3}{v_D^2}**

**Example 8**

- **W1 = 0.5 \cdot 0.8 \cdot 1^2 = 28Nm**
- **\omega = 1rad/s**
- **W2 = 300 + 0.085 + 0.8 = 9Nm**
- **M = 300Nm**
- **W3 = 37 \cdot 9 = 337Nm**
- **s = 0.025m (chosen)**
- **W4 = 44400Nm/hr**
- **L = 1.5m**
- **W3 = 2 \cdot 366 - 0.7^2 = 1494kg**
- **R = 0.8m**
- **C = 1200/hr**

**Note:** Formulae are for arm with uniform weight distribution.

9. Swinging arm with propelling force

**Formulae**

- **W1 = m \cdot v^2 \cdot 0.18 = 0.15 \cdot 1 \cdot m^2**
- **W2 = \frac{F \cdot r \cdot s}{M \cdot s}**
- **W3 = W1 + W2**
- **W4 = W3 \cdot C**
- **v_D = \sqrt{v \cdot R} = m \cdot R**
- **m_e = \frac{2 \cdot W3}{v_D^2}**

**Example 9**

- **W1 = 1000 \cdot 22 \cdot 0.18 = 720Nm**
- **m = 1000kg**
- **v = 2m/s**
- **W2 = 720 + 283 = 983Nm**
- **W3 = 983 \cdot 900 = 884700Nm/hr**
- **W4 = 2 \cdot 0.8 = 1.2 = 1.33m/s**
- **s = 0.05m (chosen)**
- **W3 = 1111kg**
- **R = 0.8m**
- **C = 900/hr**

**Notes:** Formulae are for arm with uniform weight distribution.

10. Mass lowered at controlled speed

**Formulae**

- **W1 = m \cdot v^2 \cdot 0.5**
- **W2 = m \cdot g \cdot s**
- **W3 = W1 + W2**
- **W4 = W3 \cdot C**
- **v_0^2 = \frac{C}{me}**

**Example 10**

- **W1 = 15000 \cdot 1.5^2 \cdot 0.5 = 1875Nm**
- **m = 15000kg**
- **W2 = 15000 \cdot 0.981 - 0.192 = 23367Nm**
- **W3 = 16875 \cdot 22376 = 39242Nm**
- **W4 = 39242 \cdot 60 = 2354520Nm/hr**
- **s = 0.152m (chosen)**
- **C = 60/hr**
- **W3 = 39242 + 1.5^2 = 34882kg**
Worked example

Formulae

\[ W_1 = M \cdot V^2 \cdot 0.5 \]
\[ W^2 = F \cdot S \]
\[ me = 2 \cdot \frac{W_3}{V^2} \]
\[ W_3 = W_1 + W_2 \]
\[ W_4 = W_3 \cdot C \]

Example

\[ M = 350kg \]
\[ V = 1m/s \]
\[ F = 1500N \]
\[ C = 300/hr \]
\[ S = 0.05m \] (chosen)
\[ W_1 = 175Nm \]
\[ W_2 = 75Nm \]
\[ W_3 = 250Nm \]
\[ W_4 = 75000Nm/hr \]
\[ me = 500kg \]

By comparing \( W_3 \), \( W_4 \) and \( me \) with the values in the capacity charts the correct product may be selected ie. in this instance series A type RS stock no. 834-308.

Capacity chart - self compensating

<table>
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<th>RS stock no.</th>
<th>Shock absorber Mode</th>
<th>Stroke mm</th>
<th>Max energy capacity Nm</th>
<th>Eff Weight me (kg)</th>
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