Technical explanation of vibrating magnets

Vibrating magnets are electromagnetic devices which generate a cyclical movement, when excited with an AC voltage. The vibrating frequency corresponds to the frequency of the applied AC supply. An electromagnetic vibrator is constructed by combining a magnet with masses and springs. The masses are also caused to vibrate by the cyclical motion. Therefore, these types of electromagnets are used to sieve, convey, compact etc. in feeders, vibrating tables, graders etc. The vibrating magnet works in electromagnetic vibrators without moving parts and with little noise and so in recent years they have become an important element in feeder engineering. The relevant standard for vibrating magnets is VDE 0580.

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2.1.3 Peak force $F$

The peak force is the specified power in the data sheet and therefore the power developed by the magnet.

The peak force is measured with the magnet at rest and with the rated air-gap. The published peak force value relates to a warm running condition of the magnet at 95% of the rated voltage. For temperature information see section 4.

The peak force $F$ is the force which is measured with an equivalent direct current, which has the same parting value for direct or alternating current (see VDE 0580 section 42).

2.1.4. Amplitude force $F_A$

The amplitude force is half the peak force.

$$F_A = \frac{F}{2}$$

The force with the amplitude $F_A$ vibrates around the mean value of the peak force.

The value of the amplitude force is essential for calculating the vibrating system and the deflection.

2.1.5. The rated air-gap is the published air-gap.

2.1.6. Static air-gap

The static air-gap is understood to be the clearance set between the armature and the magnet body when the system is not vibrating and in the rest condition.

3. Voltage, current, power and frequency

3.1 Voltage and current

In the case of vibrating magnets the stated voltages and currents are basically effective values. The use of the effective value is equally valid for connection through a rectifier or for connection directly to the AC supply.

3.1.1. Rated voltage

The rated voltage that is stated on the rating label is the voltage of the AC supply, which will be connected to the magnet.

The guidelines in VDE 0176 state:

"Rated voltage over 100 V".

Preferred voltages for vibrating magnets are: 220V and 380V.

3.1.2. The rated isolation voltage (series voltage) is the voltage for which the isolation, creepage and clearance are calculated. This is identical to the voltages specified in VDE 0110. The rated isolation voltages conform to VDE 0110, section 4, table 1 and these are valid for the following AC voltages:-

\[30V, \ 60V, \ 125V, \ 380V, \ 500V.\]

When there is no alternative the specified isolation voltage is designed to provide a defined isolation voltage rating for similar or lower voltage ratings.

3.1.3. The allowable continuous voltage fluctuation at the terminals of the connected equipment is +/- 5%.
3.1.4. **Test voltages.**
All magnets are tested for voltage withstand, before leaving the factory, to ensure the integrity of the magnet’s isolation.

3.1.4.1. **Type and magnitude of test voltage (Up)**
The tests are carried out with a sinusoidal 50Hz supply. The magnitude is as specified for the rated isolation voltage $U_N$.

<table>
<thead>
<tr>
<th>$U_N$ (V)</th>
<th>30</th>
<th>60</th>
<th>125</th>
<th>250</th>
<th>380</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_N$ (V)</td>
<td>Up to 30</td>
<td>&gt;30 ≤ 60</td>
<td>&gt;60 ≤ 125</td>
<td>&gt;125 ≤ 250</td>
<td>&gt;250 ≤ 380</td>
<td>&gt;380 ≤ 500</td>
</tr>
<tr>
<td>$U_p$ (V)</td>
<td>600</td>
<td>1000</td>
<td>1500</td>
<td>2000</td>
<td>2500</td>
<td>2500</td>
</tr>
</tbody>
</table>

$U_N$ (V) = Rated isolation voltage, $U_n$ = Rated voltage, $U_p$ (V) = Test voltage

3.1.4.2. **Voltage test procedure**
The test voltage $U_p$ is applied across the energising windings and the static metal parts of the device. When a greater level of isolation is provided (as in the case of encapsulated magnets when the energising windings are electrically connected through the encapsulation material) then all windings are tested for voltage withstand against each other, as well as against the static metal parts.

The test voltage is applied to the test piece at the prescribed level for approximately 1 second (short term piece test conforming to VDE 0580, section 39). The test result is accepted if there is neither breakdown nor noticeable warming of the isolation material.

3.1.4.2. **Repeated voltage test**
The factory voltage should if possible never be repeated. Under special circumstances – inspection for instance – a second test can be carried out at 80% of the value stated in the table.

3.1.5 **Current**

3.1.5.1. **Static rated current $I_{stat}$**
The value of the static rated current for magnets is measured for the rated voltage, rated frequency, 20 degrees C winding temperature and with the rated air-gap at rest.

Also the current is an effective value.

3.1.5.2. **Dynamic rated current $I_{dyn}$**
The dynamic rated current is the effective measurement taken whilst the magnet is vibrating with the rated voltage applied. (The static rated air-gap must be set when the vibrating system is at rest).

For magnets with a rectifier, working in a two mass system, with a separate frequency that is higher than the mechanical drive frequency, then it is roughly:-

$$I_{dyn} = 0.7 \times I_{stat}$$

3.2. **Power**

3.2.1. **Static power**

$$P_{st} = U_n \times I_{stat}$$

The static power of a magnet is the power with the rated air-gap (locked armature), at rest condition (not vibrating) after reaching a steady state after the reactive power has died away.

3.2.2. **Dynamic Power**

$$P_{dyn} = U_N \times I_{dyn}$$

The dynamic power is the product of the measured, effective current and applied voltage in a vibrating (dynamic) condition. The dynamic power also produces a reactive power and it is the power limit for the thermal design of the magnet and should not be exceeded in operation.
1.2.4 The surface of the iron parts has a phosphate coating for protection against corrosion.

2. **Force and air-gap**

2.1 **Force**

With vibrating magnets the force pulsates at a frequency that is twice that of the AC supply, from zero to peak value.

2.1.1 **Connection through a rectifier.**

When the vibrating magnet is connected through a rectifier the force pulses at the same frequency as the AC supply.

**Current – Time – Diagram**

\[ i = \text{peak current} \]
\[ I = \text{effective current} \]

**Force – Time – Diagram**

\[ F = \text{peak force} \]
\[ F_A = \text{amplitude force} \]

2.1.2 **Direct connection to the power supply**

When the vibrating magnet is connected direct to the supply the force pulses at double the frequency of the AC supply.

**Current – Time – Diagram**

\[ i = \text{peak current} \]
\[ I = \text{effective current} \]

**Force – Time – Diagram**

\[ F = \text{peak force} \]
\[ F_A = \text{amplitude force} \]
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8. Ordering details for vibrating magnets

1. Versions, components and construction

1.1 Versions

Magnet construction using a flat armature is tried and tested. The design is stubby so that the dimensions of the vibratory system can be kept to a minimum, whilst allowing full movement of active parts. Vibrating magnets are supplied for direct connection to the AC mains or through a rectifier.

Type code:  
Y ZA W 006....060 connection through
Y ZU W 080....170 a rectifier
W ZA W 006....060 direct connection

Encapsulated and open construction magnets are both available. However, type Y ZU W... is only available in encapsulated form.

1.2 Components and construction

Vibrating magnets comprise three main components:
   a) Magnet body (Yoke)
   b) Energising winding
   c) Armature

1.2.1. The magnet body is the part which contains the energising windings. It comprises the highly magnetic, "U" form, laminations that are assembled into an exceptionally stable core package. The core is hydraulically riveted. This enables the magnets to be used, with mechanical reliability, for higher frequencies, where there is a growing demand. Type Y ZU W... magnets have elastic hall-coil-inserts in the underside of the yoke which provide a strong, threaded hole for fixing, whilst type Y ZA W.... and W ZA W... have sturdy, mounting angle brackets which are screwed onto the yoke.

1.2.2. The energising winding produces the alternating, magnetising field. The windings are carefully produced from dynamo wire specially selected and tested for the vibratory magnetic requirements, in conjunction with a high quality isolation material. Additionally, before encapsulation the whole magnet is vacuum impregnated with a special varnish.

Most magnets are supplied with encapsulation. The sealing compound is flexible so that vibration does not cause any physical disturbance.

All connection methods have generous cross-sectional sizes. Type Y ZU W magnets are provided with a cable and earth lead for electrical connection. Types W ZA W and Y ZA W have flying leads but these can also be supplied with a cable and earth on request.

For the continuous thermal rating of the coil see section 4.

1.2.3 The armature is the part of the vibrating magnet that moves in rhythm with the vibrating frequency. It is mounted in a similar manner to the magnet body.
3.3. **Frequency**

Usually magnets are designed to run at the rated frequency of the AC mains supply of 50Hz.

Any change from the rated frequency requires different windings.

3.3.1. Vibrating magnets that are supplied for connection directly to the mains supply, have the type number W ZA W..... In this case the mechanical frequency is double that of the mains supply frequency.

\[
\text{For } f_{\text{mains}} = 50 \, \text{Hz} \quad f_{\text{mech}} = 100 \, \text{Hz}
\]

3.3.2. Vibrating magnets that are connected through a rectifier have the type numbers W ZU W..... or Y ZA W.... In this case the mechanical frequency is the same as that of the mains supply frequency.

\[
\text{For } f_{\text{mains}} = 50 \, \text{Hz} \quad f_{\text{mech}} = 50 \, \text{Hz}
\]

The power and peak force figures are given for types Y ZU W... connected through a silicon rectifier. When a selenium rectifier is used these values are reduced by approximately 10 – 15%.

4. **Duty cycle, temperature and thermal classification**

4.1. **Duty**

Essentially vibrating magnets are designed for a relative duty cycle of 100%.

4.2. **Temperatures**

4.2.1. **The reference temperature** (output temperature) is the constant running temperature under power.

The specified reference temperature (output temperature) for vibrating magnets is +35°C.

4.2.2. **The over temperature** is the temperature increase, also described as the heat rise above the reference temperature (output temperature).

4.2.3. **The final over temperature** is the over temperature at the end of a heat rise event.

The final over temperature for vibrating magnets lies below the over temperature limit for thermal class B (90 K).

4.2.4 **The temperature limit** is allowable temperature fixed for the particular component part.

4.2.5. **The over temperature limit** is the highest allowable over temperature. This is derived from the temperature limit less sum of the published reference temperature (output temperature) and the hot spot difference.

4.2.6. **The hot spot difference** is the difference between the temperature in the centre of the winding and the temperature at the highest point of the windings. A difference of 5 K is permitted.

The valid temperature used for the warmed-up working condition is the over temperature increase measured above the reference temperature of 35 degrees C.

The over temperature of vibrating magnets is determined by using the basic rated voltage, rated frequency in a static condition (locked armature), with the rated air-gap and continuous duty operation on a thermally insulated base to avoid any extraneous heating or cooling influences affecting the test procedure.

4.3. **Thermal Classification**

The isolation materials used in vibrating magnets are selected to provide a continuous, thermal stability as specified for thermal classification ‘B’.

VDE states for thermal classification ‘B’
Temperature limit 130 degrees C, or temperature limit 90 K.

In practice vibrating magnets are fitted to steel components that provide good thermal conductivity. Poor thermal conducting materials should be avoided.

5. Connection of the magnets to the power supply

The majority of vibrating magnets, of the corresponding type, are connected to the AC supply through a rectifier. In a few instances they are driven direct from the AC mains supply (refer to section 3.3.).

Variable transformers, thyristor controllers etc. are used for the stepless adjustment of the deflection.

Deflection control examples

5.1 Connection through a rectifier

a) Using a shunt resistor with the rectifier

\[ U_n \sim 50 \text{ Hz} \]

\[ f_{\text{mech}} = 50 \text{ Hz} \]

b) Using a variable transformer

\[ U_n \sim 50 \text{ Hz} \]

\[ f_{\text{mech}} = 50 \text{ Hz} \]

c) Using a thyristor control unit

\[ U_N \sim 50 \text{ Hz} \]

\[ f_{\text{mech}} = 50 \text{ Hz} \]

5.2 Direct connection to the mains supply

a) Using a Resistor

\[ U_n \sim 50 \text{ Hz} \]

\[ f_{\text{mech}} = 100 \text{ Hz} \]

b) Using a variable transformer

\[ U_n \sim 50 \text{ Hz} \]

\[ f_{\text{mech}} = 100 \text{ Hz} \]

A thyristor unit uses phase angle adjustment of the mains half-wave to control the deflection, whereas a variable transformer adjusts the height of the voltage half-wave.
6. Guidelines for the layout of the vibrating system

Most applications for vibrating magnets are in feed systems and the number of other uses is limited. Therefore, for these other applications the information is used in a different manner.

The information given in this document is provided for guidance only and depends upon the individual characteristics of each feed system. In vibratory systems there is vibratory disturbance and damping which varies from case to case. For this reason it is not possible to give valid general rules.

6.1 Feeder throughput

The feeder throughput of an electromagnetic feed system depends on the feed rate and bulk weight of the conveyed material.

The feed rate depends on the energised frequency (mechanical frequency) \( f_{\text{energ}} \), the amplitude \( A_N \), the deflection angle \( \beta \), which the tray and vibrator hinge, the tray inclination and naturally the feed material characteristics.

Accurate feeder throughput is determined by testing.

6.2 Measuring the amplitude.

The usable amplitude \( A_N \) is directly proportional to the feeder throughput and so it is an interesting thing to measure. There are several technical devices available for making this measurement, such as a vibration recorder or a wave transducer.

A very simple method is to use a paper sticker that is fixed to the vibrating component. See sketch below.

a) Diagram showing static component

Direction of Vibration

5
4
3
2
1

\( A_N \) mm

b) Diagram showing vibrating component

Direction of Vibration

5
4
3
2
1

\( A_N = 1\text{mm} \)

The vibrating component causes the wedge shape to move backwards and forwards in the direction of the arrows, thus generating an image like the one shown in diagram b). The human eye cannot differentiate between images that change at a rate greater than 20Hz and so the apparent image is like the one shown in diagram b). The length of the white triangle indicates the amplitude.

6.3 Basic calculation values

To design a vibratory drive the moving mass \( m_N \), deflection \( S \) and the energising frequency have to be known. The tuning frequency must be selected for the drive force and hence the magnet type to be determined.

Normally an uncritical tuning frequency is chosen for electromagnetic vibratory feeders, this means that the natural frequency \( f_0 \) of the total vibrating system should be higher than the energising frequency \( f_{\text{energ}} \).
Using this tuning method, the deflection (= double the amplitude) adjusts under tray loading, which varies in relation to the amount of vibration-coupled feed material, whereas additional loading causes increased damping. These two influencing factors cancel out when the tuning is uncritical thus providing limited stability against load fluctuations on the feed tray.

The following is a rough calculation which does not take into account damping etc.

6.3.1. **Design of a single mass system**

a) The known values are:

   Moving mass $m_N$
   
   Drive frequency $f_{energ}$
   
   Amplitude $A = A_N = S_N/2$
   
   Natural frequency $f_o$ through tuning

   Sought: Amplitude power of the magnet and required springs

b) The moving mass in a single mass system is normally supported by leaf-springs from a base. The amplitude $A$ is the same as the usable amplitude $A_N$, which applies only for a mass $m_N$.

c) From dynamic basics

   Drive Force – Spring Force + Mass Force = 0

   $$F_A - C \times A + m_N \times \omega^2 \times A = 0$$

   Taking into consideration the definition of the amplitude force of the drive magnet:-

   Which is:

   $$F_A = 2\pi^2 \times m_N \times s_N \times f_{energ}^2 \times (V_F^2 - 1)$$

   $F_A =$ Amplitude force of the magnet (N)
   
   $m_N =$ Moving mass
   
   $s_N =$ Usable deflection (m)
   
   $f_{energ} =$ energizing frequency (1/s)
   
   $V_F =$ Tuning constant $V_F = f_o / f_{energ}$

d) From the resonant frequency (angular velocity) it is now possible to calculate the required spring constant.

   Angular velocity $\omega_o =$

   $$\sqrt{\frac{C}{m_N}} \quad \omega_o = 2\pi f_o$$

   Natural frequency

   $$f_o = \frac{1}{2\pi} \times \sqrt{\frac{C}{m_N}}$$

   Spring constant

   $$C = 4\pi^2 \times f_o^2 \times m_N \quad (N / m)$$

   $C =$ Spring constant for the whole system ($N / m$)
Care must be taken with the mechanical configuration for multiple spring arrangements. Parallel springs are the most common and the constants for each spring are added.

Spring calculations are not given in this document but they can be found in some of the better machine building handbooks.

e) To recalculate the amplitude use:-

\[ A = A_N = \frac{F_A}{C - m_N x \omega^2} \]

\[ \omega = 2\pi f_{\text{energy}} = \text{angular velocity} \]

To make full use of the magnet if possible \( A \approx \delta \), however to prevent the armature from 'hammering' against the magnet body it should be set at \( \delta_0 > A \).

6.3.2 **Design of a two mass vibrating system**

a) The known values are:-

Moving mass \( m_N \)

Drive frequency \( f_{\text{energy}} \)

Amplitude \( A = A_N = S_N/2 \)

Natural frequency \( f_0 \) through tuning

Sought: Amplitude power of the magnet and required springs

b) With a two mass system the moving mass is usually coupled to the reaction mass through coil springs. The whole vibrating system is then supported over a base plate with soft springs. If soft support springs are used they can be omitted from the calculation.

The total amplitude \( A = S/2 \) is the same as the sum of the two amplitudes of the moving mass and the reaction base.

\[ A = A_N + A_F \]

\[ A_N = \frac{m_F}{m_N} \]

(Fundamental equations)

\( m_F = \text{reaction mass} \)

\( \delta_0 = \text{static air gap} \)

\( m_N = \text{moving mass} \)

\( C = \text{spring constant} \)

\( A_N, \delta_N = \text{usable amplitude} \)

\( A_F, \delta_F = \text{amplitude of the reaction mass} \)

From the fundamental equations it can be seen that as masses change so do their respective amplitudes. To achieve the greatest usable amplitude the largest reaction mass must be chosen. This is a question of preference, for instance:-

\[ \frac{m_N}{m_F} = \frac{3}{2} \]

The resultant mass \( m_r \) can be calculated.

\[ m_r = \frac{m_N \times m_F}{m_N + m_F} \]

The resultant mass \( m_r \) is the effective mass, that manifests itself in a two mass system.
Using the two masses and the specified usable amplitude, the total amplitude can be calculated as follows:

\[ A = A_N \frac{m_F + m_N}{m_F} = A_N \left( 1 + \frac{m_N}{m_F} \right) \]

d) From the dynamic basic equation

\[ F_A - C \times A + m_A \omega^2 A = 0 \]

To obtain the amplitude force of the drive magnet

\[ F_A = 2\pi^2 x m_r x s x f_{\text{energ}}^2 (V_F^2 - 1) \]

- \( F_A \) = Amplitude force of the Magnet (N)
- \( m_r \) = resultant mass (kg)
- \( S \) = total deflection (m) \( S = 2A \)
- \( f_{\text{energ}} \) = energizing frequency (1/s)
- \( V_F \) = Tuning \( V_F = \frac{f_0}{f_{\text{energ}}} \)
- \( \omega \) = Angular velocity

e) The required spring constant can be calculated from the resonant frequency and radial velocity of the vibrating system.

Radial velocity \( \omega_0 = \sqrt{\frac{c}{m_r}} \)

Resonant frequency \( f_0 = \frac{1}{2\pi} \sqrt{\frac{c}{m_r}} \)

Spring constant: \( C = 4\pi^2 \times f_0^2 \times m_r \left( \frac{N}{m} \right) \)

The support springs are not considered.

In the case of multiple springs the mechanical arrangement has to be taken into account.

In our example (see sketch) four springs are used in parallel and so a constant of \( C/4 \) is used, assuming that all springs are dimensionally the same.

Calculations for the springs can be found in some of the better machinery construction handbooks.

f) To recalculate the amplitude use:

Total amplitude \[ A = \frac{F_A}{C - m_r \times \omega^2} \]

Usable amplitude \[ A_N = A \times \frac{m_F}{m_F + m_N} \]

Therefore \( F_A \) and \( A \) are used for choice of magnet whereby \( A \) should be \( \leq \delta_0 \). However, when in operation the armature should not “hammer” against the magnet’s yoke.
7. **Installation Guidelines**

7.1. **Installation**
Vibrating magnets are specially designed to be used in vibratory equipment. The construction should be rigid, to reduce any stray vibration, which could seriously reduce the effective power of the magnet.

The pole surfaces should be parallel to each other in the plan view, in the rest condition, otherwise stray vibration will be created, especially if the magnet is not fitted squarely.

The force direction should if possible pass through the centre of gravity of the whole vibrating system. With a two mass system the only way to achieve precise deflection and the continuous feed of material is to ensure that the concentration of the energizing force (magnet force) passes through the centre of gravity of the complete system.

7.2. **Air-gap adjustment at rest**
The static air-gap can only ever be smaller and not larger than the rated air-gap. Enlarging the air-gap causes the current draw to increase and this can cause the coil to burn out.

Increasing the air-gap requires winding changes and causes peak output losses.

7.3. **Fitting Instructions**
The rating label details must correspond to the supply voltage, frequency and the method of connection. The magnet body must be grounded to earth.

7.4. **Protection**
An anti-surge fuse with the correct voltage rating must be used to protect the magnet against overloading.

Please refer to the manufacturer's instructions with regard to protection of the rectifier.

7.5. **Incorrect use or modification**
Any changes e.g. drilling of the housing, magnet body or armature can reduce mechanical stability. Modification of a magnet system can result in electrical problems.

In all cases the guarantee will be invalidated.

8. **Ordering details for vibrating magnets.**

   a) Type (connecting method)
   b) Voltage (V) and frequency (Hz)
   c) Peak mechanical force i.e. amplitude force (N)
   d) Air-gap at rest (stroke) (mm)
   e) Type of mounting material
   f) Ambient temperature (°C)
   g) Ingress protection level

When the magnet is to be used for a specific application, the following information is required:-

   a) Mass i.e weight that is to be vibrated
   b) Reaction mass, for a two mass system
   c) Mechanical frequency
   d) Required deflection (usable)
   e) Resonant frequency value
   f) The type of product that to be conveyed
   g) Required feed rate
   h) Tray dimensions

This will enable us to propose a suitable magnet.