Frequency Measurement

- Important electrical quantity with no equivalent in DC circuits is ***frequency***
- ***Frequency*** measurement is very important in many applications, especially in AC power systems designed to run efficiently at one frequency only
- If the AC is generated by an alternator, the **f** will be directly proportional to the shaft **N**, & **f** could be measured simply by measuring the **N** of the shaft
- If **f** needs to be measured at some distance from the alternator, though, other means of measurement will be necessary

Frequency Measurement

- **Usual Methods**

- **1. Comparison with a known frequency** – simple and common method is make use of Lissajous figures
- **2. Balancing a frequency – sensitive bridge** – make use of Wien’s or Campbell’s bridge
- **3. Indicating instruments** – use the effect of frequency upon mechanical or electrical resonance circuits, mutual inductance and other quantities which are functions of frequency

Frequency Meters

(1) Resonance Type

- **Mechanical Resonance (Vibrating Reed Type)**
- **Electrical Resonance (Ferrodynamic & Electrodynamometer Types)**

(2) Moving Coil Type

- **Electrodynamometer**
- **Ratiometer**

(3) Moving Iron Type

(4) Saturable Core Type

(5) Electronic Type

Frequency Meters

- Except vibrating reed type (mechanical resonance type) all are deflection instruments with a pointer & scale

- Moving system carries no control system, although, in some cases, coiled ligaments may be required to lead the current to the moving coils

- Deflection **frequency** meters mostly have **2** deflecting coils & resultant of **2** operating torques causes deflection

- Generally each torque is made **frequency dependent** by supplying the operating currents through circuits whose **impedances** are **frequency dependent**

Vibrating Reed Type

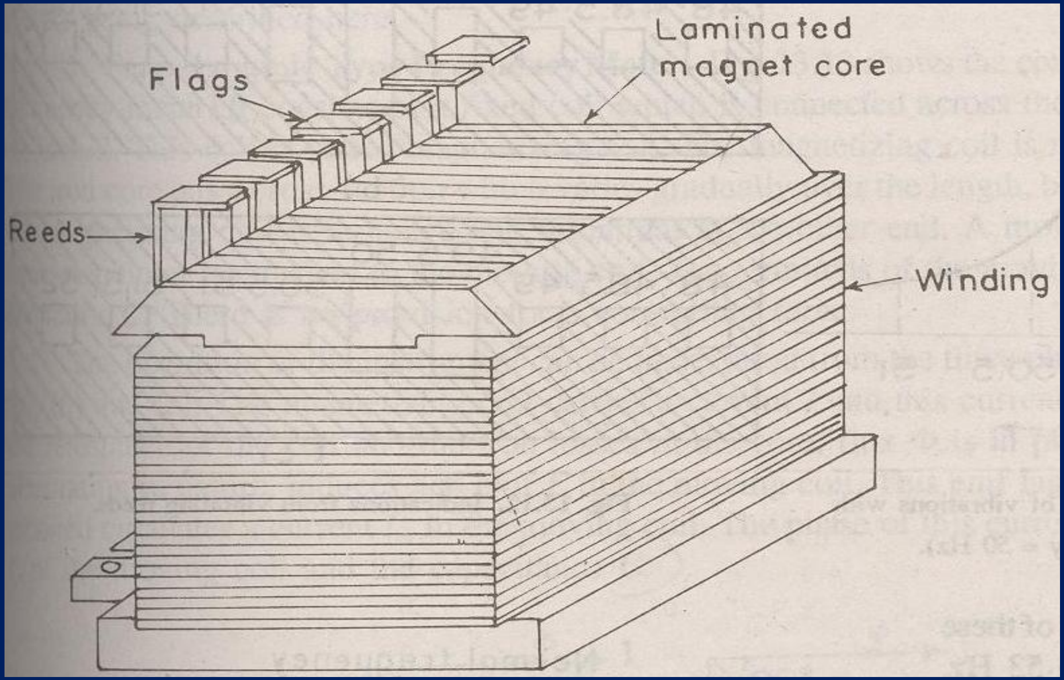
- One simple but crude method of **frequency** measurement in power systems utilizes the principle of mechanical resonance
- Every physical object possessing the property of elasticity (springiness) has an inherent **frequency** at which it will prefer to vibrate
- **Tuning fork is a great example of this: strike it once and it will continue to vibrate at a tone specific to its length**
- **Longer tuning forks have lower resonant frequencies: their tones will be lower on the musical scale than shorter forks**

Vibrating Reed Type

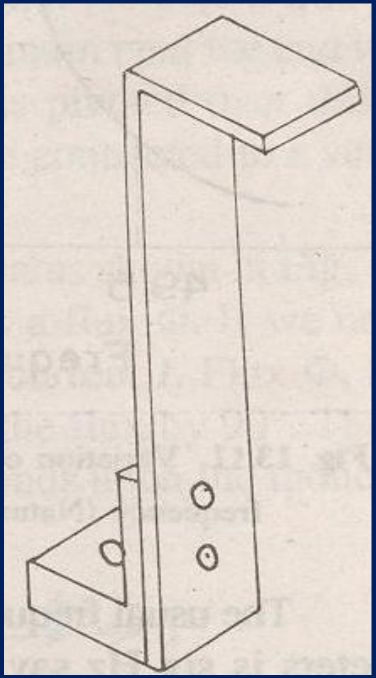
- Thin steel strips called **reeds** are placed in a row alongside close to an electromagnet
- All **reeds** are similar with their natural frequencies of vibration different and are arranged in **ascending** order of **frequencies**
- Variations in natural frequency are obtained either by variation in their lengths or by adjusting of their masses
- **Reeds** are fixed at bottom end and are free at top end with a portion bend to serve as flag

Vibrating Reed Type

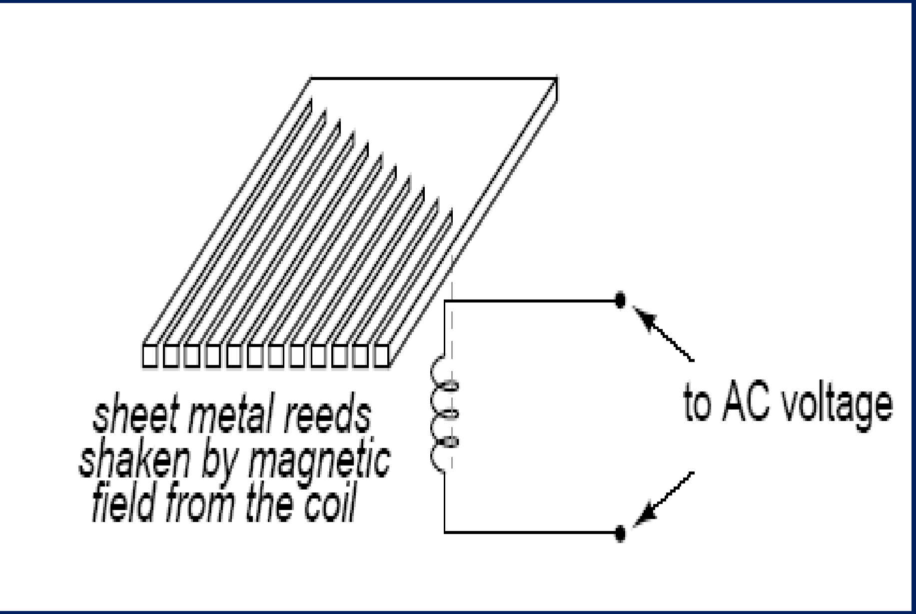
- The difference in natural frequencies of two adjacent **reeds** is usually ½
- **Reeds** are influenced, directly or indirectly, by an electromagnet's alternating field
- Core of the electromagnet is laminated and the coil is connected in series with a resistance across the supply whose **frequency** is to be measured
- The external connection is, thus, same as voltmeter

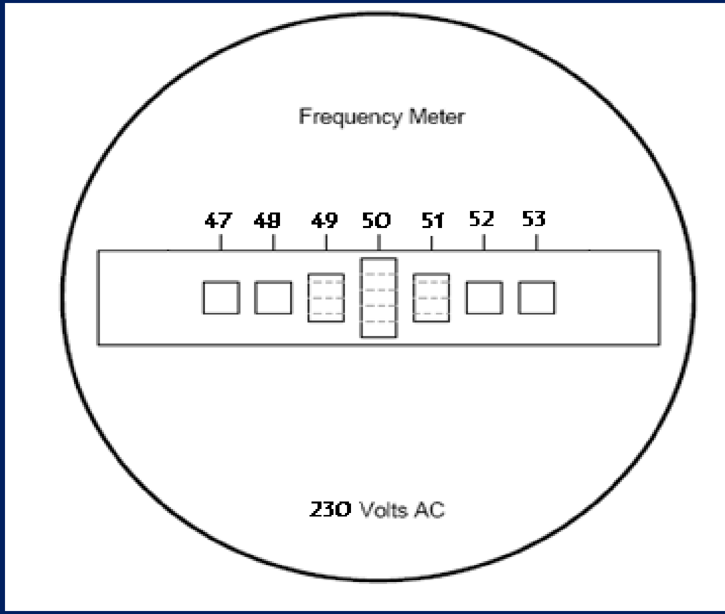


Vibrating Reed Type Frequency Meter



Reed





Vibrating Reed Type

- Coil of electromagnet carries a current *i*, which alternates at the supply **frequency**
- The force of attraction between the reeds and the electromagnet is proportional to i^2 and therefore this force varies twice at the **frequency**
- All the reeds tend to vibrate, but the reed whose natural frequency is equal to twice the frequency of supply tends to vibrate the most
- Vibration of other reeds is unobservable

Vibrating Reed Type

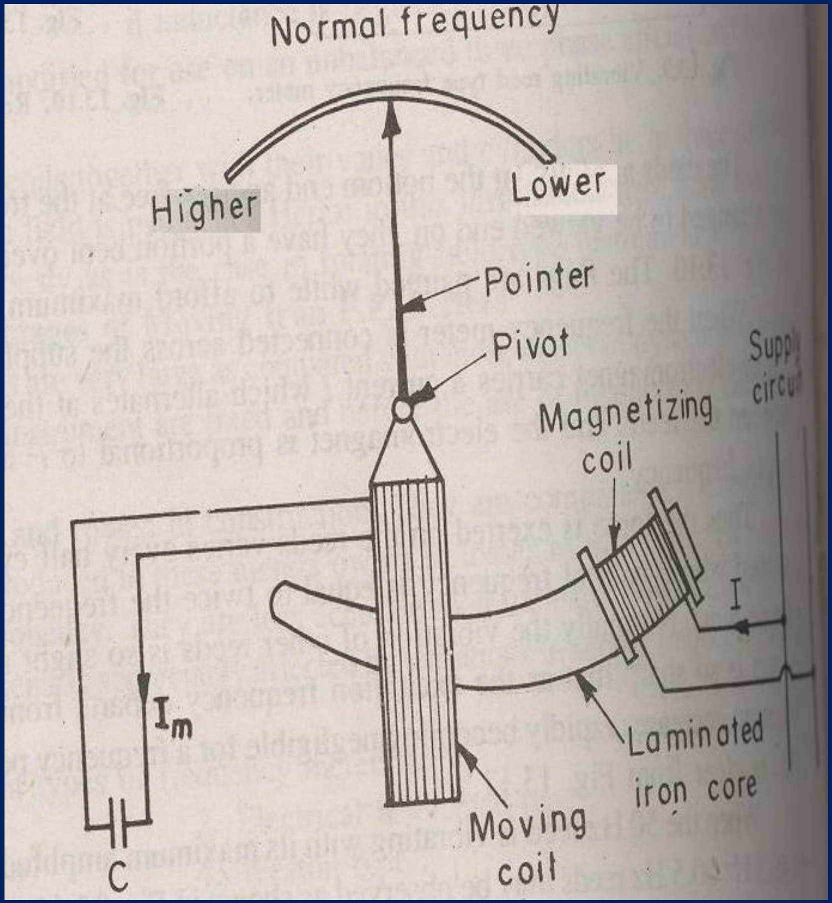
- The user of this meter views the ends of all those unequal length reeds as they are collectively shaken at the **frequency** of the applied AC voltage to the coil
- Obviously, these meters are not precision instruments, but they are very simple & therefore easy to manufacture to be rugged
- Usual range is about 6 Hz, say, from 47 Hz to 53 Hz
- Indications are independent of waveform
- There should not be too much variation in supply voltage

Ferrodynamic Type

- Operation depends on **resonance** of an **RLC** circuit
- Consists of two coils on a common laminated iron core
- Fixed coil – wound on one of its ends
- Moving coil – movable on the remaining portion of the core
- Moving coil pivoted and has a pointer attached to it and its terminals are connected to a suitable fixed capacitance C
- The fixed or magnetizing coil is connected across the supply whose **frequency** is to be measured

Ferrodynamic Type

- MC ckt is, thus, an RLC ckt, the **L** depending upon the position of the coil on the core
- It will be maximum near the magnetizing coil and minimum at the other end of the core
- C. S area of the core decreases as the distance from the magnetizing coil increases
- Fig. shows the position of mc at normal freq., & at this position, $X_L = X_C$



Ferrodynamic frequency meter

Ferrodynamic Type

- Magnetizing coil carries **I** and produces flux **Φ** in phase with **I**
- **Φ** induces emf **E** in the moving coil **lagging** behind it by 90^0
- Emf **E** circulates current I_m in the **moving coil**
- Phase of I_m depends upon **L** and **C**
- If mc ckt is inductive, I_m lags behind emf **E** by an angle α
- The torque acting on the mc is, $T_d \propto I_m I \cos(90^o + \alpha)$
- If mc ckt is capacitive, & I_m leads emf **E** by an angle β
- The torque acting on mc is, $T_d \propto I_m I \cos(90^o - \beta)$
- If $X_L = X_C$, I_m is in phase with emf **E**
- The torque acting on the moving coil is, $T_d \propto I_m I \cos 90^o = 0$

Ferrodynamic Type

- **f** increases above its normal value then, $\mathbf{X_L > X_C}$ & therefore torque produced pulls the mc to an equilibrium position i.e., mc deflects towards the section of iron core having min. cross section. So X_L decreases and mc comes to rest at a position where $X_L = X_C$.
- **f** decreases below its normal value then, $\mathbf{X_L < X_C}$ & therefore torque produced pulls the mc to an equilibrium position i.e., mc deflects towards the section of iron core having max. cross section. So X_L increases and mc comes to rest at a position where $X_L = X_C$
- **Advantage:** Great Sensitivity

Electrodynamometer Type

Fixed coil

Fixed coil is divided into two parts 1 and 2 which forms 2 separates resonant circuits

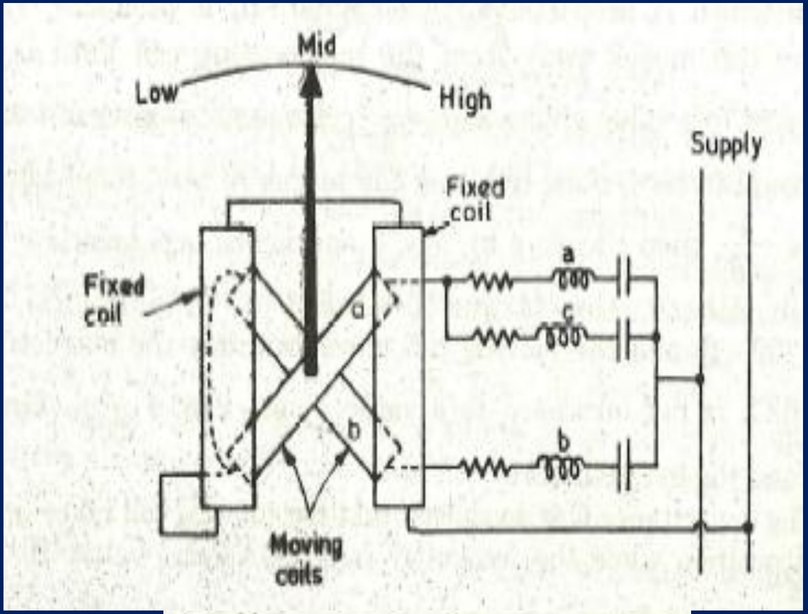
FC 1 is in series with an inductance L1 and a capacitance C1 forming a resonant circuit of frequency f1.

Fixed coil 2 is in series with an inductance L2 and a capacitance C2 forming a resonant circuit of frequency f2.

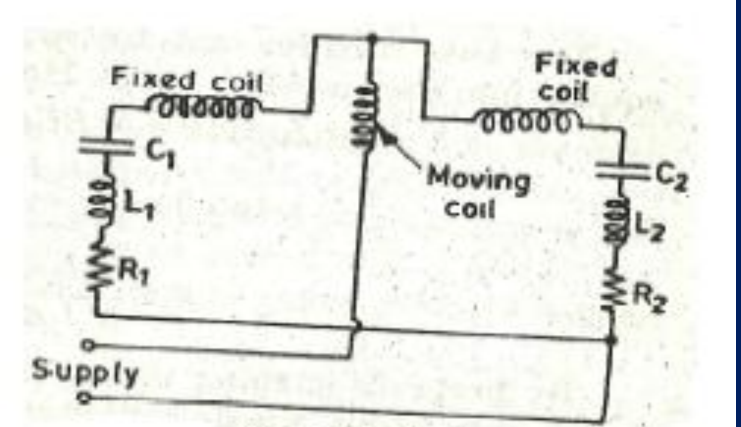
Moving Coil

Current through the mc is sum of the currents through the 2 parts of fixed coil

Torque on the movable element is proportional to the current through the moving coil



Dynamometer type frequency meter



Dynamometer type (an alternative) frequency meter

Electrodynamometer Type

- A small iron vane mounted on the moving system provides controlling torque

Operation:

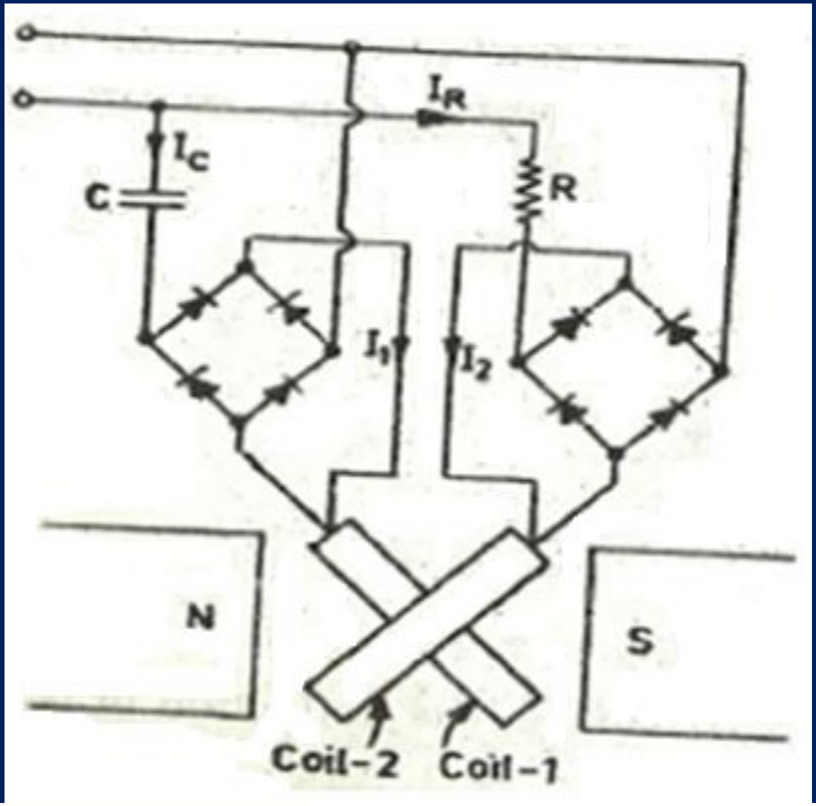
- At a particular **f**, the **I** through circuit of fixed coil 1 lags behind applied voltage (as $X_{L1}>X_{C1}$) while the **I** through circuit of fixed coil 2 leads applied voltage (as $X_{L2}<X_{C2}$)
- Therefore torques produced by 2 coils act in opposition on the moving coil
- The resultant torque is a function of **f** of the applied voltage.

Application:

- For power frequency measurements
- In power system, for monitoring the frequency

Ratiometer Type

- 2 moving coils are supplied from 2 rectifiers
- 1 rectifier in series with **R** & other with **C**
- It's a **PMMC** instrument with a difference that instead of 1 mc, there are 2 mc's attached to same shaft with an angular separation of **90^o**
- $T_{d1} = N_1 B l_1 d_1 I_1 \cos\theta$
- $T_{d2} = N_2 B l_2 d_2 I_2 \sin\theta$
- 2 torques act opposite and at equilibrium $T_{d1} = T_{d2}$



where,

N_1, N_2 = number of turns of two coils

l_1, l_2 = length of two coils

d_1, d_2 = width of two coils

θ = the angle made by coil-1 with the lines of flux.

$$N_1 B l_1 d_1 I_1 \cos\theta = N_2 B l_2 d_2 \sin\theta$$

or $$\tan\theta = \frac{N_1 l_1 d_1}{N_2 l_2 d_2}\frac{I_1}{I_2} = K\frac{I_1}{I_2}$$

where $$K = \frac{N_1 l_1 d_1}{N_2 l_2 d_2}$$

Ratiometer Type

By properly shaping the pole faces and adjusting the angle between two coils. the deflection θ can be made proportional to the ratio $\frac{I_1}{I_2}$, *i.e.* $\theta = K\frac{I_1}{I_2}$

Since the ratio of currents in two coils is measured by deflection of the instrument, the instrument is called ratiometer.

In the frequency meter of this type

$$I_1 \propto \text{input current of rectifier 1}$$
$$\propto I_C \propto V \times 2\pi fC$$
$$= K_1 VCf$$
$$\text{and } I_2 \propto \text{input current of rectifier 2}$$
$$\propto I_R \propto \frac{V}{R}$$
$$= K_2 \frac{V}{R}$$

Hence, the deflection of the instrument

$$\theta = K\frac{I_1}{I_2}$$
$$= \frac{KK_1}{K_2}\frac{VCf}{\frac{V}{R}} = K'f$$

$$\text{where, } K' = \frac{KK_1}{K_2}CR$$

- Deflection is independent of **V**, a slight variation in it does not cause any error
- But very low **V** may cause distortions giving wrong readings
- **f** range may exceed up to few kHz

Moving Iron Type

- Weston **f** meter is an example
- 2 fixed coils A & B each divided in 2 identical coils
- Coils are fixed so that their magnetic axes are perpendicular as shown
- A long and thin soft iron needle is pivoted at the point of intersection
- Spindle carries pointer & damping vanes
- No controlling system

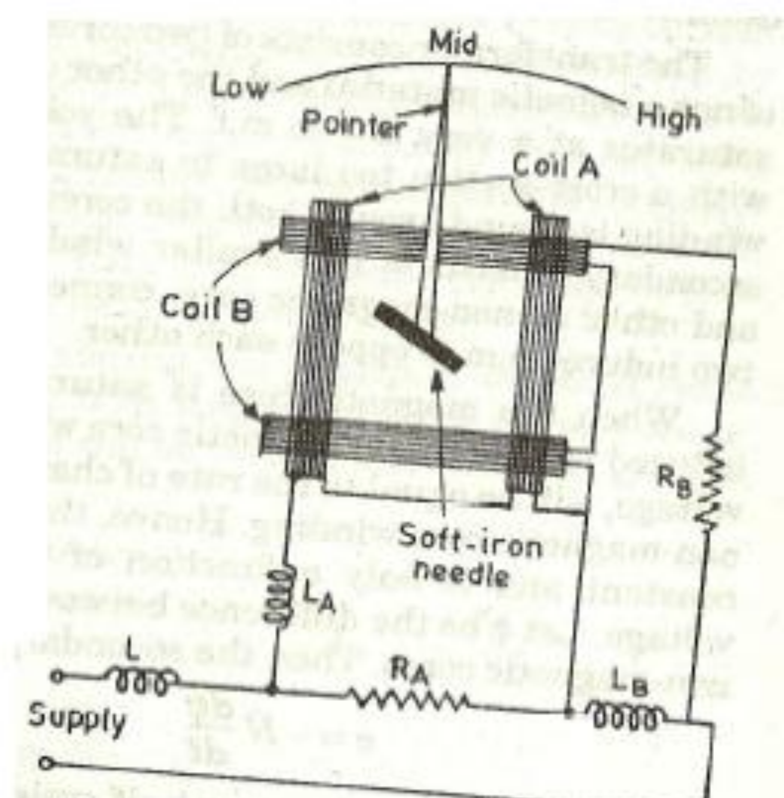


Fig. Moving iron frequency meter.

- Coil A is connected in series with L_A across a non inductive R_A
- Coil B is connected in series with R_B across L_B as shown in fig.

Moving Iron Type

- **L** is to damp out higher harmonics in supply
- Soft iron needle takes a position parallel to resultant magnetic field
- i.e. if I_A is zero then the needle becomes vertical while in case when I_B is zero it lies horizontally
- Pointer remains at center under normal frequency
- If **f** increases I_A decreases due to increase of ωL_A
- While I_B increases due to increase of ωL_B
- The effect is, therefore, to turn the pivoted needle more parallel to the axis of coil B (vertical)
- Thus the pointer is moved to right
- If **f** decreases the effect is, naturally, opposite & pointer will move to left