EXPLANATION OF THE OPERATION OF THE INDUCTION PUMP

The induction pump is just a sort of the MHD pump in which the electric field $\vec{E}$ is generated by the motional magnetic field given by the formula $\vec{E} = \vec{v} \times \vec{B}$, whereas $\vec{v}$ is velocity of shifting of the magnetic field $\vec{B}$. The drawings are needed here to visually explain exact nature of the drag created by the rotating magnetic field and this explanation is simple and initially based on the motional permanent magnets contrary to complicate one given by Nikola Tesla who is genuine inventor of the effect. His explanation is based on the stationary AC driven electromagnets making the explanation a bit confusing.

EXPLANATION OF THE ORIGIN OF DRAG FORCE AND PRESSURE CREATED BY THE ROTATING MAGNETIC FIELD

The ordinary explanation of the drag effect of the rotating magnetic field is usually confusing. The most distracting fact related to the ordinary explanation of the rotating magnetic field and the force it creates is that the effect is always treated by the concept based on stationary AC electromagnets instead of one based on the motional permanent magnets later gently replaced by stationary electromagnets driven by three phase AC currents mutually shifted for 120°. The easiest derivation of the Lorentz force is in the cylindrical symmetry with the infinite conductor with current I and a charge Q that runs parallel with the conductor. Let us assume that the good approximation of the effective charge created by Doppler's variation with the speed is:

$$Q = Q_0 \cdot \left(1 - \frac{v^2}{2 \cdot c^2}\right) \tag{1}$$

Detail explanations of this approximation's validity are available on http://www.andrijar.com/sr/sr.htm and http://www.andrijar.com/magdop/index.html. Let us further assume that the conductor is consisted of the positive charges at rest and negative charges in the motion with the speed v_e and then we have:

$$\delta Q = Q_e \cdot \left(1 - \frac{(v_Q + v_e)^2}{2 \cdot c^2}\right) + Q_p \cdot \left(1 - \frac{(v_Q + v_p)^2}{2 \cdot c^2}\right) \tag{2}$$

Whereas v_Q is speed of the free charge, v_e is speed of the electrons in the coil whose create magnetic field, v_p is speed of the protons in the coil (v_p is equal to zero because protons are at rest) and c is the speed of light.

The effective ostensible charge that appears due to the variation of the electron's charge caused by the difference in velocities of protons and electrons are:

$$\delta Q = Q_e \cdot \left(1 - \frac{(v_Q + v_e)^2}{2 \cdot c^2}\right) - Q_e \cdot \left(1 - \frac{{v_Q}^2}{2 \cdot c^2}\right) = Q_e \cdot \frac{{v_Q}^2 - (v_Q + v_e)^2}{2 \cdot c^2} \qquad (3)$$

If we assume that $v_Q >> v_e$ then we have:

$$\delta Q = -Q_e \cdot \frac{2 \cdot v_Q \cdot v_e + {v_e}^2}{2 \cdot c^2} \approx -Q_e \cdot \frac{v_Q \cdot v_e}{c^2} \qquad (4)$$

$\Rightarrow$

$$\delta Q' = Q'_M = -Q'_e \cdot \frac{v_Q \cdot v_e}{c^2} = -\frac{I \cdot v_Q}{c^2} = -\frac{I}{c} \cdot \frac{v_Q}{c} \qquad (5)$$

Whereas Q'_M is effective virtual charge responsible for the creation of the magnetic force. Further we have following formula in the cylindrical geometry:

$$F = E \cdot Q = -\frac{Q'_M}{2 \cdot \pi \cdot \varepsilon \cdot r} \cdot Q = -\frac{I}{2 \cdot \pi \cdot \varepsilon \cdot c^2} \cdot Q = -\frac{\mu \cdot I}{2 \cdot \pi} \cdot v_Q \cdot Q \qquad (6)$$

Finally:

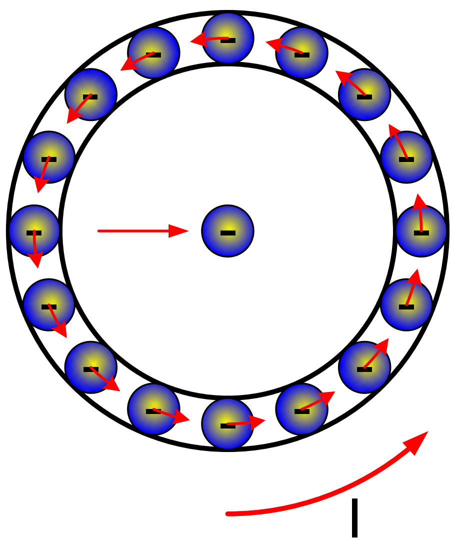
$$F = B \cdot v_Q \cdot Q \qquad (7)$$

The formula that is valid for every single case and not particularly for cylindrical symmetry is:

$$d\vec{F} = -dQ \cdot \vec{v} \times \vec{B} \qquad (8)$$

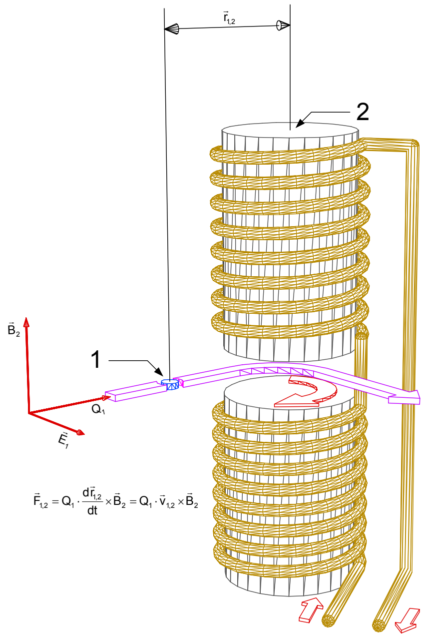
Following image depicts the charge running in gap between two magnets that create the force which tends to bend the charge's trajectory. This force is known as Lorentz's force and it is created by the variation of the charge moving with speed according Doppler's effect because the repulsing force of the approaching charge in the winding is higher than the force of outgoing charge on the opposite side of the winding whose mutual difference creates Lorentz's force that acts to the free charge:

Fig. 1



3D image of this situation is depicted on the following picture also proving that the velocity in the Lorentz formula must be determined in the respect to the magnet's windings and not in the respect to the elusive referential frame as it is commonly accepted by the relativists today:

Fig. 2

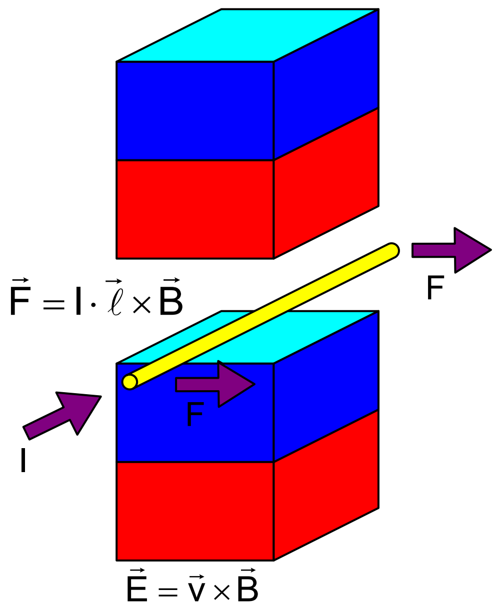


This running charge can be constrained by the conductor and then the force acting to the conductor with current I settled in the gap between two magnets is:

$$d\vec{F} = -dQ \cdot \vec{v} \times \vec{B} = -dQ \cdot \frac{d\vec{\ell}}{dt} \times \vec{B} = I \cdot \vec{B} \times d\vec{\ell} \qquad (9)$$

This is shown on the following picture:

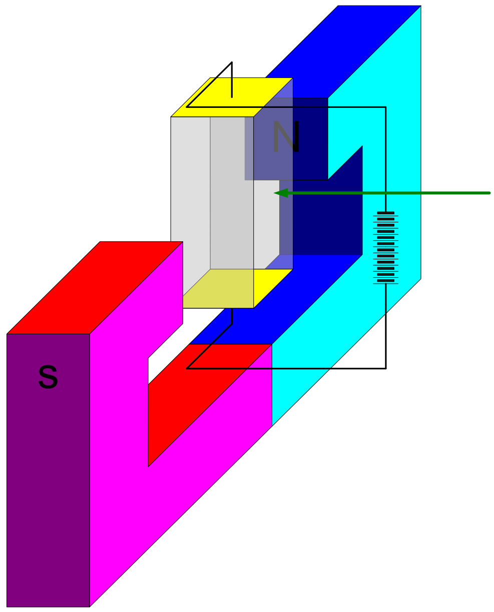
Fig. 3



Above picture shows a lateral force acting to the wire with the current.

Here is the drawing of the DC MHD cell:

Fig. 4



Connection between pressure, magnetic field and current in MHD cell is:

$$\vec{\nabla} P = \frac{d\vec{F}}{dV} = \vec{J} \times \vec{B} \tag{10}$$

For the non-conductive fluid in MHD cell permanent magnet should be replaced with the electromagnet and then the electrodes start acting as capacitor driven with the AC voltage too and then we have that the current of dipole displacement in the nonconductive dielectric fluid is:

$$\vec{J} = \varepsilon_0 \cdot \varepsilon_r \cdot i \cdot \omega \cdot \vec{E} \approx (2 \cdot \pi \cdot f) \cdot \varepsilon_0 \cdot \varepsilon_r \cdot \vec{E} \tag{11}$$

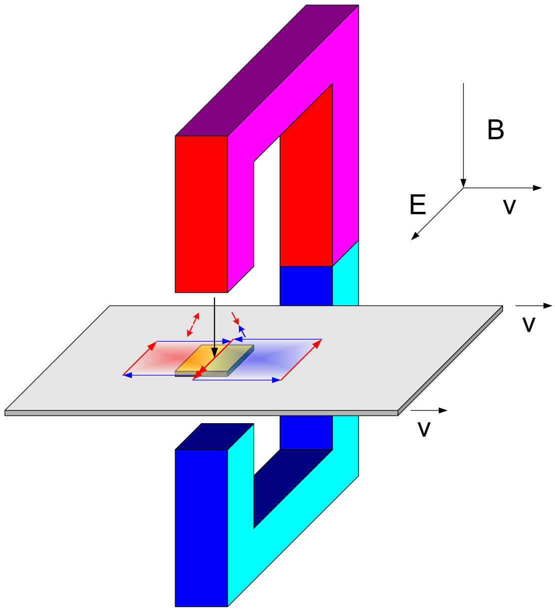
Whreas i is imaginary unit, $i = \sqrt{-1}$. Pressure in the fluid propelled by the AC MHD cell is:

$$\vec{\nabla} P = \vec{J} \times \vec{B} = (2 \cdot \pi \cdot f) \cdot \varepsilon_0 \cdot \varepsilon_r \cdot \vec{E} \times \vec{B} \tag{12}$$

This drag is purely created by the Lorentz force. For proper understanding of Induction Pump there must be explained the drag created by the rotating magnetic field on the comprehensive and simple way based firstly on the drag created by the motional permanent magnets acting to the aluminum sheet that will be later replaced with the stationary electromagnets driven by the three phase AC current acting to the liquid in the pipe.

Let us imagine the C bar permanent magnet at rest whose magnetic field pervades motional aluminum sheet on the following way:

Fig. 5



Above image depicts the C permanent bar magnet at rest and the gray aluminum sheet dragged in right direction. There are two explanations, the one based on Lorentz force created by current elements and external magnetic field and another one based on interaction between the magnet and magnetic images created in the aluminum sheet. The second magnetic explanation states that the Lorentz force creates two current's loops that further create two magnetic images from which one attracts external permanent magnet and another one repulses it creating forces' pair that is responsible for the drag effect. These zones of the magnetic field created in the aluminum sheet are denoted as faded blue and red areas encompassed by the current loops. This explanation is incomplete because appearance of currents' loops is not properly explained.

The first explanation based on Lorentz force is relying on the interaction between current elements and the external magnetic field. According Lorentz force formula created electric field in the aluminum sheet in respect to its relative velocity and the exposition to magnetic field is:

$$\vec{E} = \vec{v} \times \vec{B} \tag{13}$$

And the current density generated by the electric field is:

$$\vec{J} = \frac{\vec{E}}{\rho_\Omega} = \frac{\vec{v} \times \vec{B}}{\rho_\Omega} \tag{14}$$

Whereas $\vec{J}$ is current density running in the aluminum sheet generated by the sheet drag's velocity $\vec{v}$, $\vec{E}$ is electric field created by the electrodes, $\vec{v}$ is velocity of the aluminum sheet, $\vec{B}$ is magnetic field of the C permanent magnet and ρ_Ω is the electric resistivity of the aluminum sheet. Resistivity ρ_Ω is reciprocal conductivity σ_Ω of the medium:

$$\sigma_\Omega = \frac{1}{\rho_\Omega} \tag{15}$$

The electric current propelled by the Lorentz force is split into two asymmetric loops outside the magnetically directly pervaded zone. Their asymmetry is caused mainly by Doppler's effect, but the currents outside the zone exposed to the external magnetic field do not produce the force due to the absence of the external magnetic field and therefore they do not create the drag force. The drug force is created exclusively by the current running trough the zone (yellow) on the sheet pervaded by the external magnetic field:

$$d\vec{F} = dQ \cdot \vec{v} \times \vec{B} = \vec{J} \times \vec{B} \cdot dV = \frac{\left(\vec{v} \times \vec{B}\right) \times \vec{B}}{\rho_\Omega} \cdot dV = \frac{\left(\vec{v} \cdot \vec{B}\right) \cdot \vec{B} - \vec{B}^2 \cdot \vec{v}}{\rho_\Omega} \cdot dV \tag{16}$$

In this case we have two stages effect where the relative velocity between the aluminum sheet and the magnet induces electric field that then creates current which generates drag force. The current based explanation seemingly contraries the explanation based on the magnetic images because in that case the drag force is created by the entire current's loop creating encompassing magnetic image that then creates the force that acts between the image and the external magnet. It is interesting that it is not experimentally resolved which explanation is truly correct one yet. Tons of papers are wasted to repeatedly prove that the force is equal in both cases, but this equality in force does not imply that the explanations are identical: the force is either localized in the area exposed to the magnetic field or it is not – it cannot be both at the same time! The experiment is going to be very simple and it is shameful that no one has performed it yet although almost 130 years passed since the effect was discovered. However, Lorentz based explanation seems to be more viable and theoretically correct, but it still needs to be experimentally approved simply by the foil able to change the color according to the magnitude of the external magnetic field locally exposed.

It is assumed that relative velocity of the sheet is perpendicular to the magnetic field that pervades the medium, i.e. $\vec{B} \perp \vec{v}$, and then equation (16) becomes:

$$d\vec{F} = -\frac{\vec{B}^2 \cdot \vec{v}}{\rho_\Omega} \cdot dV \tag{17}$$

Whereas $\vec{F}$ is drag force, $\vec{J}$ is current density, $\vec{v}$ is velocity of the aluminum sheet, V is volume of the aluminum sheet exposed to the magnetic field (yellow cuboid on the above picture) and ρ_Ω is electric resistivity of the medium, i.e. aluminum sheet.

Final equation is:

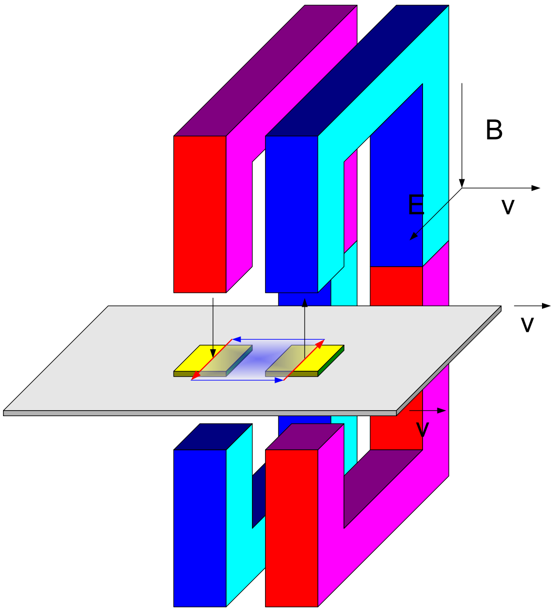
$$\vec{F} = -\frac{\vec{B}^2 \cdot \vec{v} \cdot V}{\rho_\Omega} \tag{18}$$

Above equation states that resistivity and conductivity plays significant role in the creation of the drag force in the medium. With the increase of the electric resistivity of the medium we need to augment both magnitude of the magnetic field $\vec{B}$ and the relative velocity $\vec{v}$ of the magnet in respect to the exposed medium. The aluminum sheet may be replaced with the pipe filled with conductive fluid and then the pressure of such pump is given by the following formula:

$$\vec{\nabla}P = \frac{d\vec{F}}{dV} = \frac{\vec{B}^2 \cdot \vec{v}}{\rho_\Omega} \tag{19}$$

We do not want to have currents' contours freely shaped by Doppler's effect and therefore we will diminish its influence by the confining of the current with opposite adjacent magnets:

Fig. 6



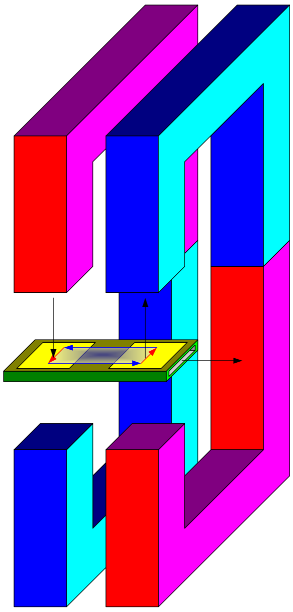
In that case we have almost completely confined electric current that creates a current loop occupying two magnetically pervaded areas and creating an image of the magnet settled right between these two permanent magnets which cancels most of the influence of the Doppler's effect on the magnetic image creation. The image's magnet created by the current loop in aluminum sheet attracts one magnet and repulse another one creating drag and its position is slightly affected by the Doppler's effect creating nonlinear dragging effect.

Drag force is created only by the current paths perpendicular to the conductor (vertical red arrows) and in this case it is doubled:

$$\vec{F} = -\frac{2 \cdot \vec{B}^2 \cdot \vec{v} \cdot V}{\rho_\Omega} \tag{20}$$

The section of the pipe in which the drag is obtained by the pulling of magnets across the pipe is:

Fig. 7



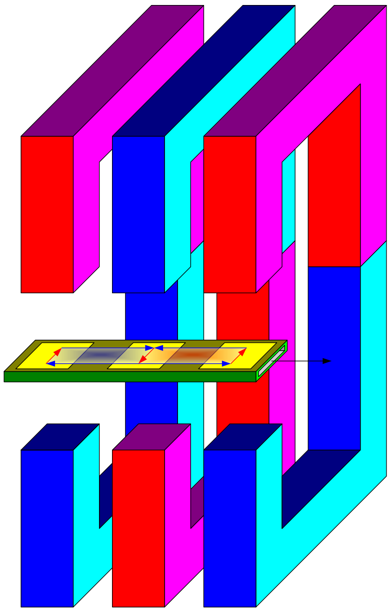
In this case of two magnets the pressure is also doubled:

$$\vec{\nabla}P = \frac{2 \cdot \vec{B}^2 \cdot \vec{v}}{\rho_\Omega} \tag{21}$$

Whereas $\vec{v}$ is relative velocity between magnets' couple and the fluid in the pipe.

By adding of the third magnet we would obtain the case of the three phase linear asynchronous pump:

Fig. 8

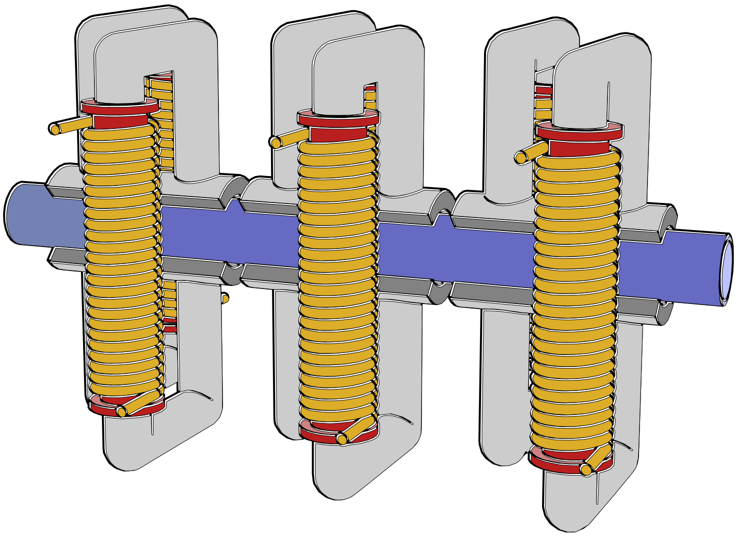


In the case of the pump we cannot make such rings and therefore we must rely to the analogue to the concept of the AC motor with the homogenous rotor which yields the pressure:

$$\vec{\nabla}P = \frac{3 \cdot \vec{B}^2 \cdot \Delta\vec{v}}{\rho_\Omega} \tag{22}$$

Whereas $\vec{v}$ is relative velocity between the shifting speed of the magnetic field and the speed of the running fluid and d is distance between magnets. The motional magnets can be replaced with the stationary magnets and then we have:

Fig. 9



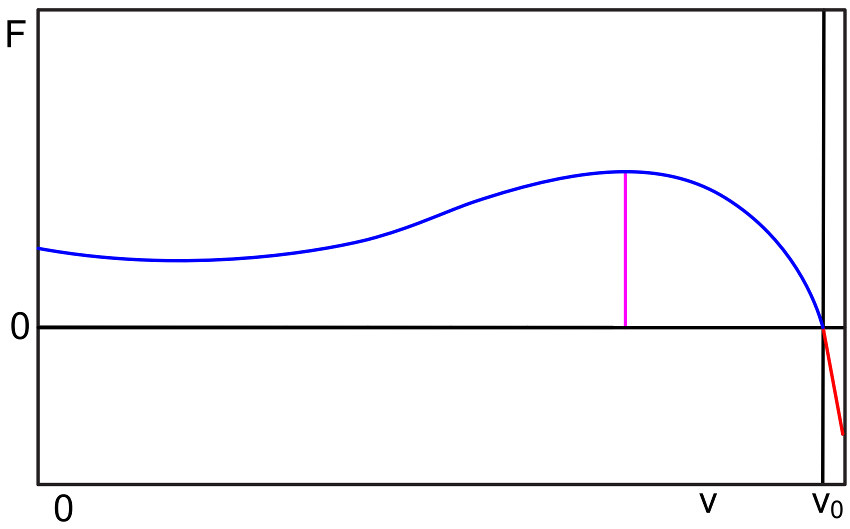
Non-infinitesimal equation is:

$$P = \frac{3 \cdot B^2 \cdot d \cdot (v_f - d \cdot f)}{\rho_\Omega} \tag{23}$$

Whereas v_f is the speed of the fluid in respect to the pipe, d is distance between magnets and f is frequency of the AC current in the electromagnets.

The pressure will not linearly follow velocity on high speed because the inductive resistance will diminish the pressure in regards to the following graph:

Fig. 10



Above graph really challenges Lorentz force based explanation of the rotating magnetic field's drag, but we can assign this discrepancy to the increase of inductive resistance of the medium that follows increase of the frequency. Another less straight explanation is that the image of the magnet is slightly affected by the Doppler's effect that distorts the image canceling the drag force.

In the case of the dielectric fluid we have that the pressure per a magnet is:

$$\frac{\partial P}{\partial \ell} = \frac{2 \cdot \pi \cdot \varepsilon_0 \cdot \varepsilon_r \cdot B^2 \cdot v^2}{d} \tag{24}$$

Whereas v is relative speed between the fluid and the field and d is distance between the magnets. If there is excitation extra frequency we have that is:

$$\frac{\partial P}{\partial \ell} = \frac{(2 \cdot \pi \cdot f) \cdot \varepsilon_0 \cdot \varepsilon_r \cdot B^2 \cdot \Delta v}{d} \tag{25}$$

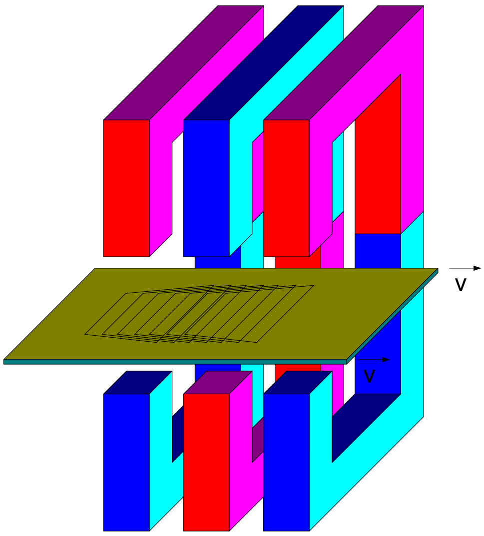
And:

$$P = (2 \cdot \pi \cdot f_e) \cdot \varepsilon_0 \cdot \varepsilon_r \cdot B^2 \cdot d \cdot (v_f - d \cdot f_0) \tag{26}$$

Whereas f_e is frequency of excitation, f_0 is basic frequency, d is distance between magnets and v_f is speed of the fluid. The curiosity is that the vacuum also has ε_0 is dielectric permittivity and therefore the drag of vacuum could be expected too.

Tesla did not stop here and he made one ultimate confining of the currents in the rotor on the following way: the aluminum sheet may be represented as the set of rings mutually insulated and settled on the nonconductive gray plate:

Fig. 11



This construction is called Cage Rotor Asynchronous Motor because these rings resemble to the cages and Tesla preferred this type of AC motor's rotor as it is described in his initial patent of rotating magnetic field (see US PAT 382279). The width of the ring should be equal to the distance d between the magnets. In the case of the cage rotor the current may flow strictly trough the rings obtaining the best possible drug force. If the ring is printed on the multilayer PCB then we have the case of the printed AC motor. In reality the motional permanent magnets are replaced by the three stationary AC electric magnets driven with the three phase AC current producing magnetic fields identical to ones of motional permanent magnets. By this conceptual visualization various interesting patterns in the cage rotor could be contrived bringing potentially significant advance in both efficiency and elasticity of the AC motor torque. Presence of the non-conductive ferromagnetic material in the sheet facilitates creation of magnetic images amplifying the drag force.

All the drawings are idealizations and in reality the gaps in the magnetic circuits should be maintained as narrow as possible.

As it is shown in the above text the induction pump is just a sort of contactless MHD pump in which two stages process is going on: firstly magnetic field creates electric current and then the same magnetic field affects this just created electric current producing the drag of the medium via Lorentz force, which is essentially different than DC MHD where the individual electric and magnetic fields are separately inserted into the medium.

ADVANTAGE OF THE THREE PHASE SYSTEM ELECTRIC GRID

At the very beginning of the electric grid there was a war between Edison's DC and Tesla's AC systems. The advantage of the Edison system was much better utilization of copper wires that was able to transfer double energy for the same cross section in respect to the mono-phase AC system and the disadvantage was usage of the inefficient rotary voltage converters. The advantage of the Tesla's mono-phase grid system was absence of moving parts and usage of efficient transformers with disadvantage of low utilization of electric wires.

At the moment Tesla utilized the mathematical identity that is $COS(\theta)+COS(\theta+120^{\circ})+COS(\theta+240^{\circ})=0$ due to symmetry in the coordinate system. Let us imagine one pair of electric wires and then let us split this pair into three new pairs, and let we shift the current phase in the second pair for 120˚ and in third pair for 240˚, and then let we join one wire of all three pairs together – for symmetrical electric consumer the current trough this joined pair will be zero according abovementioned trigonometric identity. By this operation we have just canceled three wires doubling the utilization of the copper in conductors and equalizing the efficiency of AC electric grid with the DC one. At the moment the destiny of the electric grid system was cemented and doomed to be three-phase AC grid only.

The torque of asynchronous and synchronous AC motors is constant which improves longevity of the gearboxes and also they do not contain noisy sparkly brushes. The disadvantage is low elasticity in respect to the linear DC motors which can be mitigated by the usage of frequency controllers.

Dipl.-Ing. Andrija Radović
E-mail: andrijar@andrijar.com
http://www.andrijar.com
Tel: +381 64 1404075