Physical Aspects of Practical Applications of the Virtual Conductor Magnetic System, VCMS.

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1. Introduction

Conception of VCMS was offered by one of the authors in 2002 as an alternative to developing classical force acting on a powered conductor in a uniform magnetic field [1]. At that time, it was an alternative solution to develop an apparatus flying in Earth's magnetic field [2].
Today's permanent 1 T magnets contain an equivalent of hundred thousands or even millions amps inside. But, being placed in the uniform magnetic field, the bar magnet experiences a torque rather that a net force.
VCMS converts the torque into the net force with no mechanical parts.

Later, the system of VCMS elements was called a Magnetic Propeller. The experiments on it had proved its feasibility and it was then reported at AIAA Conference in 2008 and in other sources [3,4,5].
Theoretical aspect of equivalency of VCMS to a regular powered conductor in the magnetic field also was proved in [6].

2. Major Physical Concept of VCMS

Fig.1 shows a general concept of VCMS.

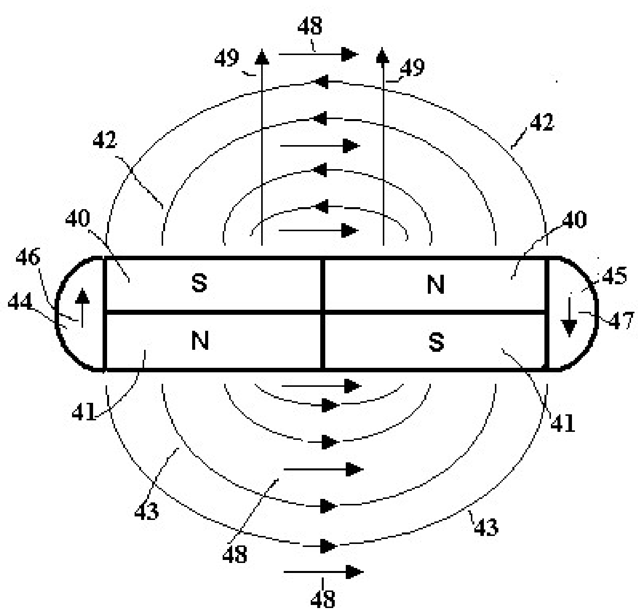


Fig.1. General concept of VCMS (according to [1,3,4,5])
Notations: 40 - bar magnet; 41 - bar magnet, having magnetic moment, which is anti-collinear to the magnetic moment of the magnet 40; 42 - magnetic field of the magnet 40; 43 - magnetic field

of the magnet 41; 44 - left magnetic shunt for “absorbing” end magnetic field of the magnets 40-41; 45 - right magnetic shunt for “absorbing” end magnetic field of the magnets 40-41; 46 = left-end magnetic field inside the shunt; 47 - right-end magnetic field inside the shunt; 48 - external magnetic field; 49 - net force.

The net force for this system was derived then as

$$F_n = \iint_S \Delta w(x,y)\,dS = F = \frac{kB_E B_M S}{\mu_0 \mu_r} \quad (1)$$

Action of this force is equivalent to some efficient current I_{eff} along some efficient conductor l_{eff}. Therefore,

$$F = \frac{kB_E B_M S}{\mu_0 \mu_r} = I_{eff}\left[l_{eff} \times B_E\right] \quad (2)$$

Here: B_E and B_M are inductions of the external field and the magnets, respectively; *K*-a technical factor, related to geometry of the system, *S*-active area, μ_0 and μ_r-magnetic permeability of vacuum and the magnet, respectively, I_{eff} –the efficient current, developing a net force, l_{eff}- a length of the efficient conductor.

The experiments with the system of Fig.2 had proved feasibility of this conception [3,4,5]. The 1*T* VCMS developed 0.012 *N* force in 3.0e-3 *T* uniform magnetic field, developed by Helmholtz coils, Fig.2. The VCMS was placed at the center of the coils on a spacer between it and the electronic scale. The red arrow on the VCMS marks direction of its own field. The switch on the left portion of the powering box changes direction of the 3.0e-3*T* field inside the coils.
The necessity of employing that week external field is caused by targeting the goal to develop a system to fly in Earth’s magnetic field of 3.0-6.0e-5*T*.
At that experiment, the efficient length was 25mm.
Fig. shows a visualization of magnetic lines of force for the VCMS used in that experiment. The efficient length was 25mm (a length of the central dark line), so this VCMS is equivalent to a conductor of that length.

Fig.2. Experiment with VCMS (at the centre) in a uniform (3 mT) field of Helmholtz coils.
The VCMS is located on electronic balance, separated by a neutral spacer. The left switch atop of the pedestal changes direction of the external 3 mT field. The red arrow on VCMS shows a direction of its own field.

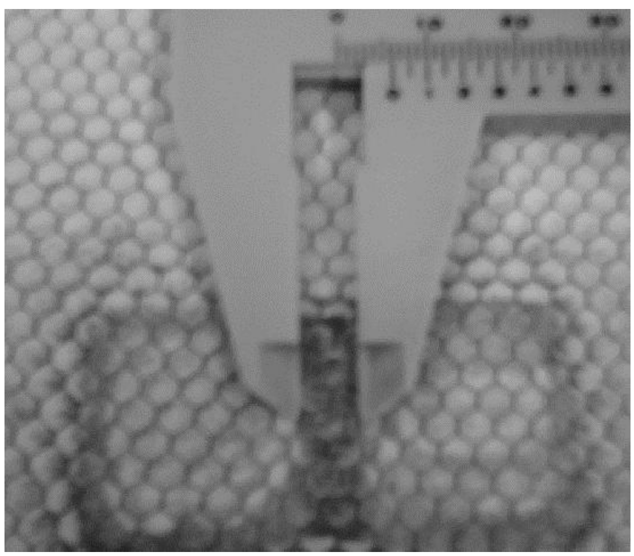


Fig.3. Image of magnetic fields of VCMS on the magnetic imager. The caliper shows the efficient magnetic field around the manifested virtual conductor. No magnetic shunts are installed and the side fields are also visible. The efficient length of the virtual conductor is a width of this assembling, 25 mm.

Therefore, the maximal efficient current at mutual orientation of the fields like in Fig.1 is

$$I_{eff} = \frac{kB_E B_M S}{\mu_0 \mu_r l_{eff} B_E} = \frac{kB_M S}{\mu_0 \mu_r l_{eff}} = \frac{kB_M d}{\mu_0 \mu_r} = \frac{F}{l_{eff} B_E} \quad (3)$$

Where d is an effective diameter of the virtual conductor.

On the other hand, the efficient current can be defined from the experiment, by having the resulting force, the external field and the equivalent length of the VCMS.
According to the parameters of the experiments above, the efficient current was 160 A.

3. Efficiency of the VCMS

The efficiency *Eff* shows what the portion of the hidden Ampere's currents is converted into the current, producing the net force rather than a torque. It can be estimated as the efficient-to-full current ratio for the total currents of 2 magnets:

$$Eff = \frac{I_{eff}}{2I} \quad (4)$$

The full current can be estimated basing on a magnetic energy of the magnet if to represent it as a conductor having an inductivity *L*. Basing on that

$$W = \frac{LI^2}{2}, \quad (5)$$

the total current of the magnet is

$$I = \sqrt{\frac{2W}{L}} \quad (6)$$

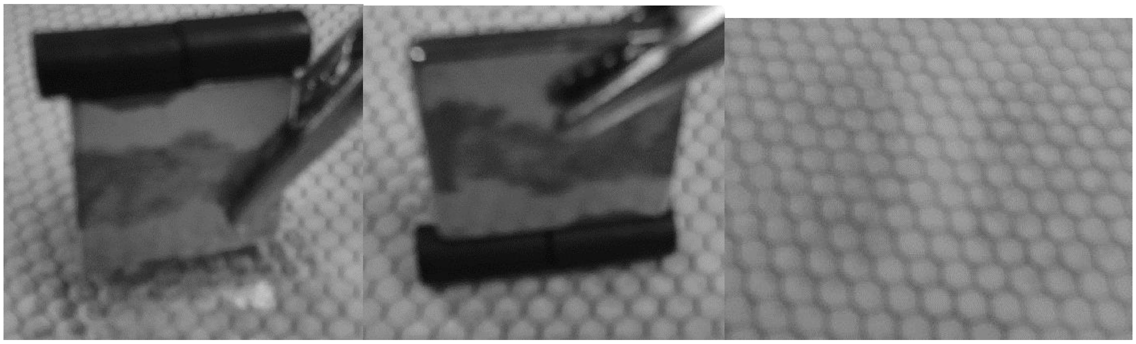
Average density of energy of today's rare Earth magnets is as much as $480 kJ/m^3$ (Sm_2Co_{17})
The volume of the magnets of the Fig. is $3.1\times10^{-6}/m^3$, that is, each of them contains ~ 1.5 *J* of magnetic energy.
The inductivity *L* (measured in *H*) of the virtual conductor visible on the Fig. can be calculated from a general formula for a single straight conductor, [7,p.30]

$$L = 2\times10^{-9} l\left(\ln\frac{4l}{d} - 1\right), \quad (7)$$

Where *l* and *d* are a length and diameter, measured in cm.
For the virtual conductor of the Fig.3, *l=2.5 cm.*, it returns *L=1.0e-8 H*
The total current of one magnet of VCMS of Fig. is *1.73e+4 A*
Having the calculated I_{eff}*=160 A* from the experiment, the efficiency of the VCMS of Fig. is *Eff=0.46%.*

4. The Ways of Increasing the Efficiency

Such the low efficiency, lower than that of a steam locomotive, is explained, in particular, by that VCMS of the Fig.1 did have adequate magnetic shunts.
A role of the shunt is shown in Fig.3 where it absorbs the end magnetic lines of force.



a

b c

Fig.4. Effects of the magnetic shunt: **a-** no shunt at the lower and of the magnetic field is visible on the imager as a dark area; **b-** the shunt at the lower portion of 1T magnet; **c-** the imager shows no imprint of the magnetic field at the lower portion of the magnet, after removal the magnet according to part b.

A proper magnetic shunting can increase the efficiency up to 2 times.
Geometric factor is another resource to increase the efficiency. In formula ( ) it's represented by a factor K which varies within 1-2. Decreasing a thickness of the magnet increases a share of the external magnetic lines of force, playing an active role in developing a thrust.
All these measures together can increase the efficiency up to several times.

5. Accompanying Factors

A group of the associated physical phenomena has to be taken into consideration for implementation of a feasibility of this conception.

1. Torque;
2. Need of stabilization;
3. Motion-induced current;
4. Demagnetizing.

Crossing magnetic lines of force by VCMA will cause the induced current which can demagnetize the system. To reduce this, the VCMS has to be composed of thin plates like it's employed in transformers to reduce the eddy currents.
But even this measure does not eliminate completely the motion-induced current, which has a natural displacement component $\partial\vec{E}/\partial t$ as a result of originated vortical electric field $\boldsymbol{E}$ which can vary.

6. Physical Aspects of VCMS-Based Apparatus

VCMS, placed in magnetic field will experience a torque, due to conditions of the minimum of the free energy and due to the phenomenon, considered in [3,4,5] and related to a hysteresis of the magnetic system. This is why a practical application will require stabilizing like it was proposed in 8-shape current system of the [2,3,4,5]
A heavy bar magnet can work as a stabilizer.

Fig.5. shows a general physical conception of VCMS based apparatus, which develops both vertical and horizontal thrust in the external magnetic field. Mechanical linkages are not shown. Two VCMS provide difference of densities of the total magnetic energies in their vicinities developing the thrusts. To stabilize a position of the system in the external field, the bar magnet works as a stabilizer.
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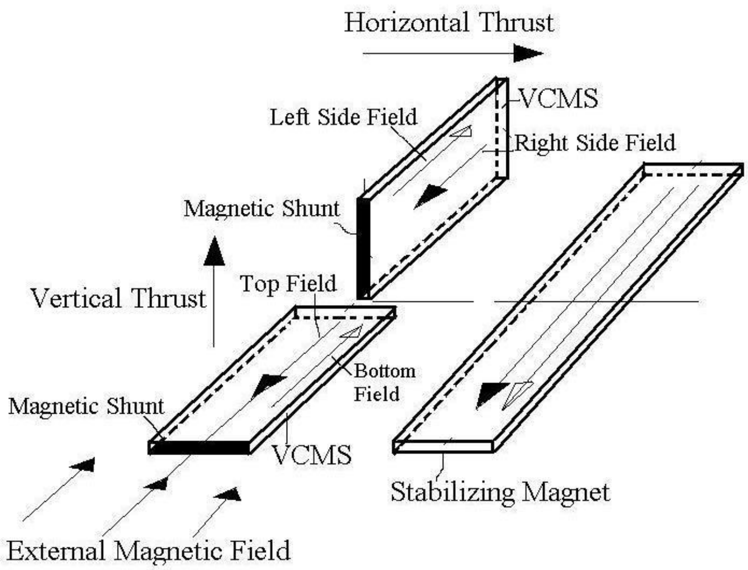

Fig.5. A general physical conception of VCMS based apparatus, which develops both vertical and horizontal thrust in the external magnetic field. Two VCMS provide difference of densities of the total magnetic energies in their vicinities, developing the thrusts. To stabilize a position of the system in the external field, the bar magnet works as a stabilizer. Mechanical linkages are not shown. In a real apparatus, the horizontal thrust VCMS can be installed atop of the vertical thrust VCMS.

7. Power Consumption.

Total work, performed by the external magnetic system to move VCMS is furnished by a portion of a mutual magnetic energy of the external field and VCMS. This energy transforms into kinetic energy of accelerated VCMS.
The energy of the magnetic source, scattered as the virtual conductor passes a distance X inside the field $\boldsymbol{B_E}$, can be calculated as

$$A_x = \int_0^{\Phi_{max}} I_{eff}(x)d\Phi = B_E \cdot l_{eff} \cdot \int_0^x I_{eff}(x)dx = B_E \cdot l_{eff} \cdot \int_0^x I_0 e^{-kx} dx \qquad (8)$$

Where **Φ** is a magnetic flux, defined as a product of an external induction by an area, covered by the effective conductor as it moves inside the field.

8. Practical Applications.

Magnetic launcher is one of the possible applications.

One of the problems of existing Magnetic launchers is a heavy current of powering rails and the problems related to that [8].

VCMS is free of these disadvantages.

Getting 500 A of the efficient current VCMS is real today. A system, having leff=1m can develop 500 N of both horizontal and vertical thrusts in 1 T field.

Experiments with VCMS, including the weight reduction and the linear motion can be found in [9-11].

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