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Subject: Energy Density in Permanent Magnets

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Every one knows permanent magnet's can convert mechanical energy into electrical energy. This paper provides some idea as to the shape and volume of the permanent magnetic (PM) required to deliver ~7.8Kwatt-hours of electrical power to a resistive load. The energy density or energy product of a permanent magnet (PM) can be determined from the B-H diagram, chart of the permanent magnet type selected. [1] The energy density of the PM is referenced to a volume of 1 cubic meter, (m^3) and the units are in Joules.

The basic equation is: Energy Product = $B \cdot H$

Where,

B = flux density of the permanent magnet at Bm1 units, gauss.

H = demagnetizing force units, H-Oersteds.

A typical PM example, Type EEC NEOL6 has the following capability:

B = 2000 gauss

H = 625 H-Oe.

Therefore the Energy product (E_p) = 1250000 gauss-oersteds or 1.25×10^6

Now we need to convert the energy to Joules per cubic meter. This conversion factor is listed as 125.63 gauss-oersteds = 1 joule per cubic meter. [2]

Then $E_p = 1.25 \times 10^6 / 125.63 = 9.9498 \times 10^3$ joules per m^3 . This gives us the PM energy density in Joules for the NEOL6 example above [3]. Now we must find the energy density of a PM made from NEOL6 and who's pole cross-section is estimated to be 3.4 cm^2 . Then consider a cube, equal on all sides, so the volume is computed to $39.304 \times 10^{-6} \text{ m}^3$.

Next we need to find the energy density of this PM.

Then we use the energy density per m^3 which is , $9.9498 \times 10^3 \times 39.304 \times 10^{-6} = 0.3912$ joules. This is the static energy density coming off the poles or surface of the permanent magnetic. At first, this looks like very little energy, but this is the static flux energy equivalent. Using the Sines power converter method, the goal is to switch the static magnetic flux so that we can modulate this energy and couple it to a coil where this energy can be directed to a resistive load. High speed switching of the flux will provide the means to convert this static flux into the power necessary to drive even Kilowatt loads. This is the only way this PM could perform this feat. The PM must be switched at some high rate, effectively providing small packets of energy to the load.

As an example, if one could switch the static flux of a PM at a 20KHz rate with a 50% duty cycle. Then this works out to a switching period of 50×10^{-6} seconds. Since all power converters have two parts to their switching cycle, then the period is cut to ~25usec each. This means that we can now multiply the static magnetic flux (Joules) by the operating frequency, (Hz), because this is number of switch cycles in 1 second. While were doing this, we might as well compute the energy density for the most common frequencies found in the US and the world. These are 400 Hz and 60 Hz and these frequency will be compared to 20KHz to give you some kind of a perspective as to how high frequency switching modifies power density.

Therefore, the joule conversion, **Less Losses** is estimated to be:

| Joules | Switching Rate of Frequency, Hz |
|--------|---------------------------------|
| 7821 | 20,000 |
| 156 | 400 |
| 24 | 60 |

We can see that as we raise the operating frequency we can convert more static flux. This is the amount of energy that could be delivered in 1 second. Now we need to convert this energy to watt-hr's, so we need to multiply this number by 3600 seconds to equal 1 hour and then convert the units to watt-hours using the conversion factor 0.0002778. This is not bad power density when you consider the size of the cube, which is about the size of a nickel in diameter and height.

| Watt-Hours (1 cube) | Switching Rate of Frequency, Hz |
|---------------------|---------------------------------|
| 7821 | 20,000 |
| 156 | 400 |
| 24 | 60 |

Then if you could fill 1 cubic meter with the NEOL6 PM cubes and switch them at the above rate you would be able to convert the following watt-hours. Note that it takes 25,442 cubes to fill a 1 cubic meter with the PM example above. Therefore, the following applies.

| Watt-Hours (1 Cubic meter (25,442 ea.)) | Switching Rate of Frequency, Hz |
|---|---------------------------------|
| 199 e106 | 20,000 |
| 4 e106 | 400 |
| 610 e103 | 60 |

So how much energy could you get out of a box say, 9 Inches cubic at these frequencies.

| Watt-Hours (9 Inch Cube (84 ea.)) | Switching Rate of Frequency, Hz |
|-----------------------------------|---------------------------------|
| 656.964 e103 | 20,000 |
| 13.104 e103 | 400 |
| 2.016 e103 | 60 |

This computation will vary since the application still needs some work, but this gives you some idea as to what the conversion rate could be, provided the right operating conditions. That's a lot of energy to run coffee pots or other devices hungry for electrical power!

- [1] Permanent Magnet, Design and Application Handbook, ISBN 0-89874-863-1, 1985
- [2] Soft Magnetics Application Guide, Arnold Magnetics Group, p.30-8, Feb 2003 Rev. B
- [3] EEC NEOL6 PM, Manufactured by Electron Energy Corporation, Landisville, PA 17538