As a peculiarity, it is possible to further increase the efficiency of the motor by increasing the cross section of the conductor's coils without any loss of field, as the anisotropic behavior of the compounded coils maintains the conductor cross reluctance constant against the width of the conductive ribbon.

This freedom of design provides a unique chance to reduce the coils resistance arbitrarily, whilst keeping the Bl value and the moving mass of the system unvaried. Some tests have been performed and they confirmed the possibility to design this device in a way that can exhibit values of Motor Strength above 12,000 (Bl of 20N/m and coils resistance of 30 milliOhm).

This is a very important point, in fact, the performances of a moving magnet transducer depend on the capability to accelerate the "load" fast enough to provide the power bandwidth for a certain application. Some of the real world samples tested, with a specific design of the coils and yoke allows the motor to achieve a Peak Force to Mass ratio of 6500N/Kg of magnet, over a linear displacement of 30 mm peak to peak. This level of displacement can be requested in extremely high SPL applications up to 100 Hz. Different dimensioning of both the coils and magnets can further increase the excursion capability. This is still a trade-off between low frequency maximum output level and power bandwidth, as it happens with conventional moving coils.

The limit of the Peak Force to Mass ratio also comes from the properties of the magnet material; highly coercive materials with high Energy Product clearly deliver the best performances and it appears a promising technology, with further developments in near future. The trend of magnet performances envies a constant progress toward extremely high-energy product compounds, improving the results even further.

Another crucial feature of this motor design is represented by the fact that the design of the yoke shape permits magnetic centering of the moving parts. In this way it is possible to create a magnetic restoring system that acts like a mechanical springs.
The nature of any magnetic circuit seeking the lowest energy condition, allows geometric definition through the shape of the coils and the magnets, creating a pulling profile that pull back the moving parts to the rest position. An "end of stroke" non-linear behavior of these magnetics springs can provide a steeper fall of compliance toward the extreme displacements condition, behaving as a gentle limiting action in the event of over excursion situations.

4. GENERAL SUBWOOFER DESIGN WITH T/S PARAMETERS

The general approach to subwoofer design is based on Thiele and Small parameters to calculate the acoustic transfer function of the loudspeaker transducer combined with its box, in addition to impedance curve, cone excursion and other performance parameters. The use of T/S parameters has been diffused since the late 70's and it represents a very simple and practical method that is largely embraced by most of the loudspeaker designers.

Anyway, the traditional approach to the using of the T/S parameters is aimed to optimizing box parameters to hit a desired target acoustic response. For the vented box design, for examples, very often a maximally flat response is desired down to some possible LF extension, sometime else it is desired an acoustic transfer function with more gentle roll-off, or alternatively, the maximum possible low frequency extension with under-damped design and some limits of acceptable ripple in the response. These targets can be achieved with a number of box Volume (Vb) + Tuning Frequency (Fb) + Loss Factor (Qb) combinations, eventually assisted by some electronic high pass filter with some specific response shape determined by the filter Q. Closed box design, could be also approached in a similar way and also in this case, a number of possible "alignments" could be found interesting for the target frequency response. There are a number of additional LF box design that may use the closed box and vented box design combined together or combined with other acoustic loading. I all these cases, the traditional design approach aims to make the LF system delivering (with some approximations) some desired target acoustic frequency response, regardless the amplifier that will be used to drive it. Typically, this frequency response will be maximally flat down to the low cut frequency point.

So, whatever it is the desired target response, this approach is intended to design a subwoofer that can be eventually driven by any generic amplifier available, in a classic "Voltage Driven" approach, where the amplifier is considered an ideal voltage source with the minimum possible output impedance, and where the overall result will be very similar, regardless the specific amplifier that is going to be used to drive it. This approach has been widely developed during the years, from when the very low output impedance amplifiers based on solid-state circuitry are available.

And following this approach, in order to match easily the typical target acoustic response, the transducers should usually have a preferred set of parameters. For example, in a typical vented box design, a moderately low Qts (0.25 to 0.42) is desired to easily achieve good and flat LF extension while keeping box dimensions relatively small.

So, the optimal transducer to mate with this approach will have a set of parameters that will be very different from those of a very high efficiency loudspeaker. Both Don Keele and John Vanderkoy, several years ago, they have already shown the eventual advantages (and disadvantages) of very high efficiency loudspeakers based on very high Bl (very high Motor Strength) design. Beside the substantially higher efficiency of these designs, in fact, there are some disadvantages if they are driven very from a standard and low output impedance amplifier available on the market, especially if they are based onto traditional analog design.

Very high motor strength transducers, in fact, will show an impedance curve around the resonant frequency that could be extremely high, even with low values of voice coil resistance (Re) thus resulting in a very low sensitivity in their low frequency range and they require very high voltage level to be driven. In addition to that, such transducers will be very reactive producing a considerably high level of back e.m.f. that will result in a large amount of dissipated heat in the output stage of linear amplifier designs. This “over-damped” behavior might also result in a lack of feeling (and perception) of the bass range, also with appropriate voltage driving, because the electrical damping effect of the back e.m.f., it will act like a strong electro-mechanical brake on the cone movement.

So, a new perspective for high performances and high efficiency subwoofer designs was offered by the availability of switching amplifiers design (also referred as Class D amplifiers) that, for instance, are perfectly able (with some attentions) to manage large amount of back e.m.f. arriving from the loudspeakers and are also able to take advantage of recycling it into the power supply.

In addition to this, with the designing of specific dedicated amplifiers capable of very high output voltage, the necessary voltage to drive these transducers will not be a problem anymore.

Last, but not least, if the dedicated amplifier design will have an adjustable output impedance that can be eventually set to a desired value, different from zero, the “amplifier + transducer” combination the loudspeaker behavior can eventually be changed to match a specific acoustic design. The adjustable output impedance will work as a “virtual output resistance”, changing the amplifier to transducer interaction without any power loss. The overall system can still take advantage of the very high efficiency of an over-damped transducer but the resulting transfer function and system damping can be set to a specific desired behavior.

5. SUBWOOFER DESIGN USING THE NOVEL MOVING MAGNET DESIGN

Subwoofer design with the novel moving magnet transducer largely refers to the concept expressed into the last part of the previous chapter. The moving magnet design, in fact, being a very high motor strength transducer, it may feature a Bl^2/Re that can easily range between 2000 and 4000. This is a characteristic of a highly over-damped transducer and it is almost one order of magnitude higher than that of a normal moving coil loudspeaker in the market. In fact, normal values of Bl^2/Re for moving coil transducers can range from a minimum of 20 for very simple woofers or mid-bass to about 150 of high power subwoofer transducers, and up to about 500 of very high Bl, large format, very high power subwoofers.

For instance, the T/S parameters of two typical large format, moving coil transducers units for subwoofer application like 18” and 21” nominal diameter could be similar to these:

For a typical 18”:

- Fs = 35 Hz
- Re = 5 Ohm
- Bxl = 26 Tm
- Sd = 1225 cm^2
- Qts = 0.31
- Qes = 0.32
- Qms = 7.2
- Vas = 230 Lt
- Mms = 200g

- Xmx = +/- 10mm
- Vd = 1.22 Lt
- Le = 1.8mH
- Bl^2/Re = 135

For a typical 21”:

- Fs = 30 Hz
- Re = 5.5 Ohm
- Bxl = 34.5 Tm
- Sd = 1730 cm^2
- Qts = 0.26
- Qes = 0.27
- Qms = 6.1
- Vas = 375 Lt
- Mms = 315g
- Xmx = +/- 12mm
- Vd = 2.07 Lt
- Le = 2.5 mH
- Bl^2/Re = 216

Using such moving coil transducers to design a vented box, for instance, we could consider the following logical path:

a) Analysis of the target parameters: frequency response limits and final box dimensions

b) Analysis of the parameters that the possible transducer should have to fit with our needing

c) Analysis of the transducer limits and optimization of the design in order to maximize total output

d) Final calculation of the box parameters, eventually considering some help from external electronic to take care of driver excursion limits

e) Eventual final frequency response and phase response optimization with a dedicated DSP.

So, in the case of normal transducers that feature a moderate motor strength and a normal level of electroacoustic efficiency we could easily find that each size of transducer would lead us to a box sizes and relative tuning that will stay inside some regular ranges that will be adequate to not generate too much pressure inside the box and to accommodate for reasonably sized vents, and the resulting acoustic output will be relatively flat, down to the low cut frequency.

Alternatively, in the case of using a very high motor strength transducer, we could find that following the same procedures we may end up with results that need to be carefully considered. A subwoofer design that uses such a kind of transducer, in fact, it needs to be analyzed and to have targets parameters set under a different perspective. For instance, as it can be easily verified with a simulator or with practical experience, if we design a vented system using an highly over-damped transducer to obtain a simple, maximally flat, high pass characteristic, we could end up with a box that features a very small internal volume. In some cases this volume would be so small that it cannot even allow to have the transducer physically mounted into it, and with a high pass roll off point well above the frequencies of interest. Moreover, in order to produce very high acoustic output level this loudspeaker system needs to “move” a considerably high quantity of air, generating unconventional pressure inside the box and unwanted high speed of air into the vents. So, let’s give a look at a typical parameters of the moving magnet design, both with a 22” and a 30” cone attached:

Moving Magnet motor with 22” cone attached:

- Fs = 36 Hz
- Re = 0.26 Ohm
- Bl = 24 Tm
- Sd = 1661 cm^2
- Qts = 0.15
- Qes = 0.15
- Qms = 7
- Vas = 50 Lt
- Mms = 1501g
- Xmx = +/- 25mm
- Vd = 4.15 Lt
- Le = 5.9 mH
- Bl^2/Re = 2215

Moving Magnet Motor with 30” cone attached:

- Fs = 30 Hz
- Re = 0.26 Ohm
- Bl = 24 Tm
- Sd = 3420 cm^2
- Qts = 0.16