# A Saturable Inductor Circuit Without Loss

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Following our discussions on Saturday, March 9 2002, at LBNL, I have thought some more about what would happen if no damping resitor is used. The result looks almost too good to believe, so I am sketching my thinking in this note.

I realize that the real circuit is more compicated than the one I analyse, but the real circuit may behave in a similar way. In any case it would be something worth simulating or modeling.

I will assume:

- A single compression stage;
- Negligible cable distance from driver to kicker;
- A sudden saturation at $I_s$ from an initial large inductance $L_1$ to a small inductance $L_2$;
- A purely inductive kicker magnet with inductance $L$;
- I start the clock at t=0 with the drive capacitor $C$ charged to $V_o$ and no current flowing.

Initially, we have a simple resonant ciruit with a long time constant $\tau_L$

$$\tau_L \ = \ \sqrt{(L + L_1)C}$$

The voltage $V_1$ across the capacitor starts to fall:

$$V_1 \ = \ V_o \ \cos\left(\frac{t}{\tau_L}\right)$$

The Voltage $V_2$ accross the kicker is proportional to $V_1$, but much smaller

$$V_2 \ = \ V_1 \ \left(\frac{L}{L + L_1}\right)$$

and the current $I$ in both inductors starts to rise:

$$I \ = \ I_o \ \sin\left(\frac{t}{\tau_L}\right)$$

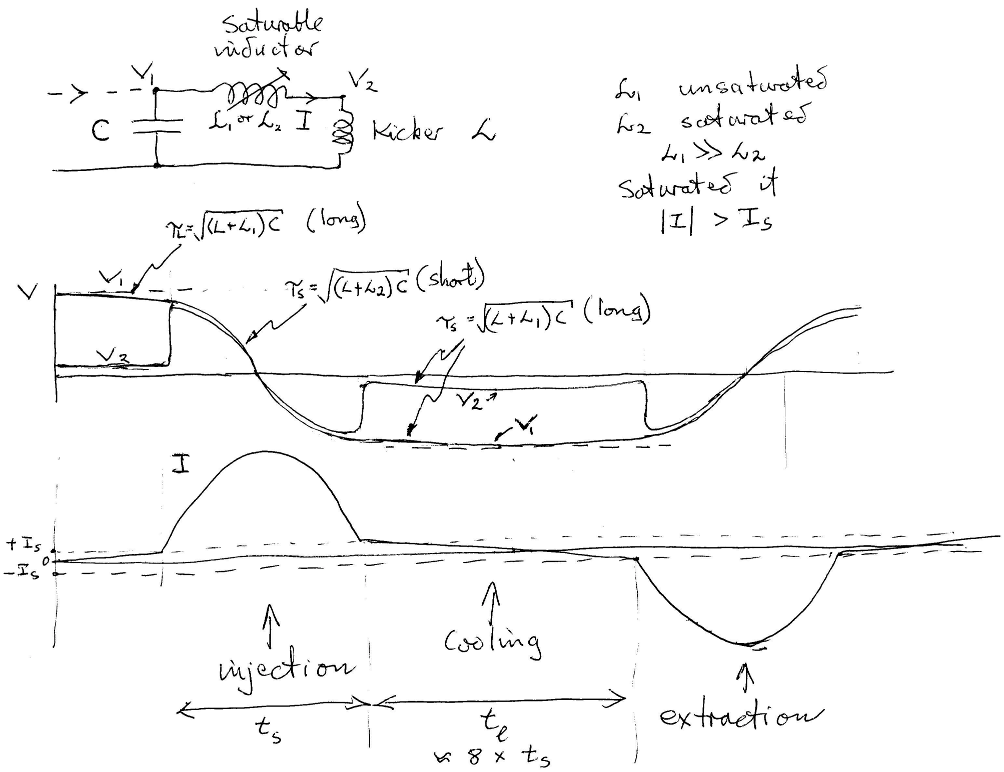
But when the current rises to the saturation current, then the saturable inductance falls to a much smaller value $L_2$ and the oscillation frequency becomes much higher:

$$\tau_S = \sqrt{(L + L_2)C}$$

and the voltages and currents almost finish their first $\pi$ phase of their oscillation at this faster rate. This gives the required unipolar kick for the injection. But the $\pi$ phase oscillation will not quite finish at the high rate. Just before the current goes to zero, the current falls below its saturation value and the saturable inductor regains its high inductance. The oscillation then slows to the earlier long time constant.

Thus is generated a pause during which the current remains small and the voltage on the capacitor remains large and negative. Suitable choices of parameters should be able to make theis pause equal to the required time between injection and extaction ($\approx 8 \times$ injection pulse length). Eventually, after the current has reversed sign, it will reach again the saturation value. Then starts the second almost full $\pi$ of oscillation at the higher freqency, and this can be used for the extraction.

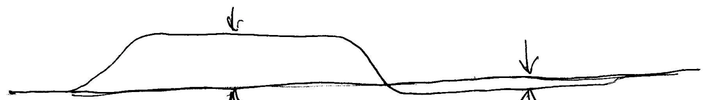
Let me here add some hand drawn sketches of what I think the pulses should look like. Note that, for ease of drawing, I have made the pause between injection and extaction much shorter than it would really be.



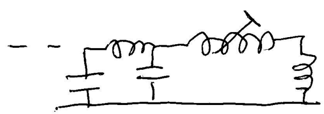

With no losses, the system would continue to deliver spaced positive and negative pulses for ever. In reality they would die away long before the next bunch 20 msec later.

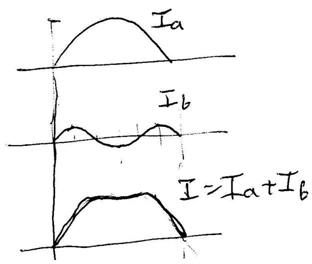
Refinements

① Drive pulse, length ~ $t_L$ should have an overshoot to correct for losses before extraction




② Drive C should be replaced by circuit with higher harmonic (3x) to generate "flat" top






Can the third harmonic flat top generation be obtained with such a simple circuit modification?

Will it still work for the more complicated multistep compression systems?

If it does, then we seem to reduce the stored energy requirement by about four: a factor of 2 from the lossless use of the initial strored energy, and another factor of two because we get the extraction for free.

To see how many units we then require, I need to know how much stored energy is available if the system is NOT terminated. Perhaps this is the same as that which you quoted delivered to the resistive load, but I am not sure. It is, for instance, hard to believe your load was strictly resistive

Cheers Bob Palmer