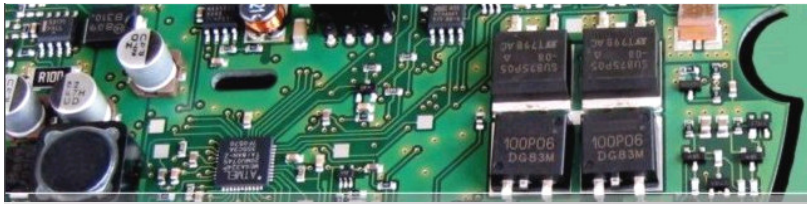


EMEKO and

Avoiding of Transformer Inrush currents with a Transformer–Switching-Relay TSR, and an Explanation of the physical basics of transformers. Speech to explain the Softstart procedure of the TSR.

This Speech give answers to the following questions:

What is an transformer inrush current peak, what is his origin?

What is the function, the advantages and the application of the Transformer-switching-relay, a low cost softstarter for Transformers?
What happens inside of the transformer while continuos running and if switch him on?

To understand the causes of the inrush current, you need an understanding of the physically basics of the transformer and how does it function:

a.) while continuous run, b.) when switching him off, c.) when switching him on.

d.) The difference between Inrush current- Limiting and avoiding.

This explanation is following in the first part of this speech.

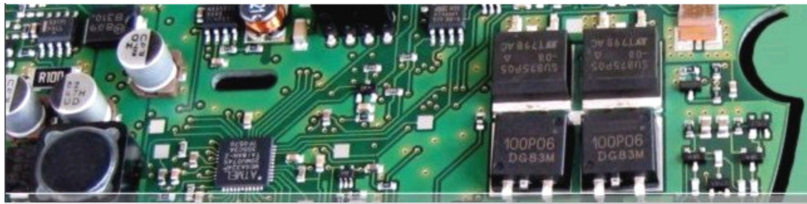
Transformers always are producing inrush current peaks!

Nearly everybody knows that!

Just when switching on a transformer, sometimes the fuse trips and sometimes he stay ok. Why?

(The fuse in the picture has a value of 0,8A and was double of the nominal current, of the transformer, but although, he trips after any time, because of the overcurrent stress.)

More than double of the nominal current is not enough!!



EMEKO and FSM

Particularly toroidal core transformers must have oversized fuses.

absich-v-rktr-ohn.xls

Ohne Einschaltstrombegrenzung

230V Primär				automaten			Schmelz-Sicherung		PKZM-	PKZM-T	PKZM-T
Trafo-Typ	Leistung	strom Pr.	Inrush	B-Char.	C-Char.	K-Char.	5 * 20 m		Bereich	Bereich	Einstell
	VA	A	A peak	A	A	A	A	A	A	A	A
Ring-Kern	500	2.17	300	-	50	40	-	-	/	10 - 16	10
Ring-Kern	800	3.48	350	-	63	50	-	-	/	16 - 2	16
Ring-Kern	1000	4.35	400	-	-	50	-	-	/	20 - 20	20
Ring-Kern	1250	5.43	500	-	-	63	-	-	/	-	-
Ring-Kern	1600	6.96	600	-	-	-	-	-	/	-	-
Ring-Kern	2000	8.70	800	-	-	-	-	-	/	-	-
Ring-Kern	2500	10.87	1000	-	-	-	-	-	/	-	-

An 1kVA Transfo must have an 20A PKZM-T line breaker, and therefore a value of 5 times of the primary nominal current.

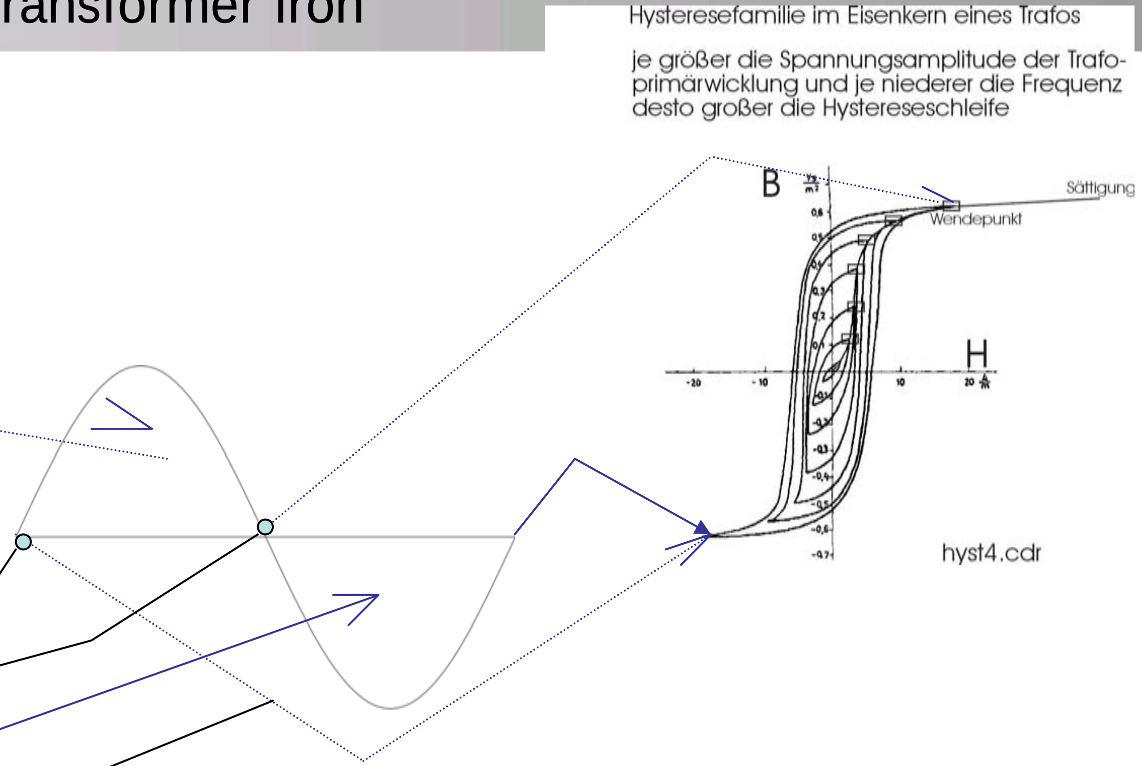
Without avoiding of the insrush current that leads to foolish fuse values. An 1600VA or bigger toroidal Transformer size is not fusible with elements listed in top.

What happens in the transformer iron core-1:

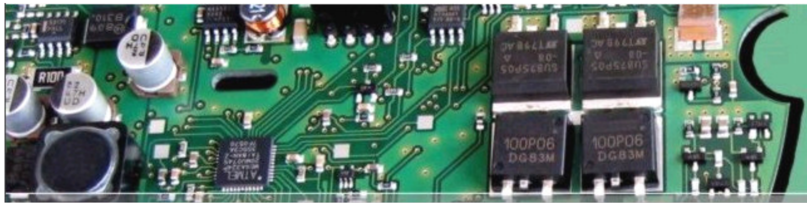
While continuous operation:

The primary voltage cycles are changing the dense of magnetisation B, in a permanently manner.

- The positive Voltage-halfcycle transports the amplitude of the magnetisation B, from the negative to the positive return point of the hysteresic loop, reaching it at the end of the pos. halfcycle.
- The negative Voltage-halfcycle, brings back the B to the negative returning point of the hysteresic loop.
- And so on and on.



Only the voltage-time-area of an Voltage half wave **is responsible for this transportation of the B**. (The no-load-primary current is only the answer from the transfo.) With the voltage-time-area of a fullwave, see on top, the amplitude of the magnetisation B, walk round the hysteresic loop one time.



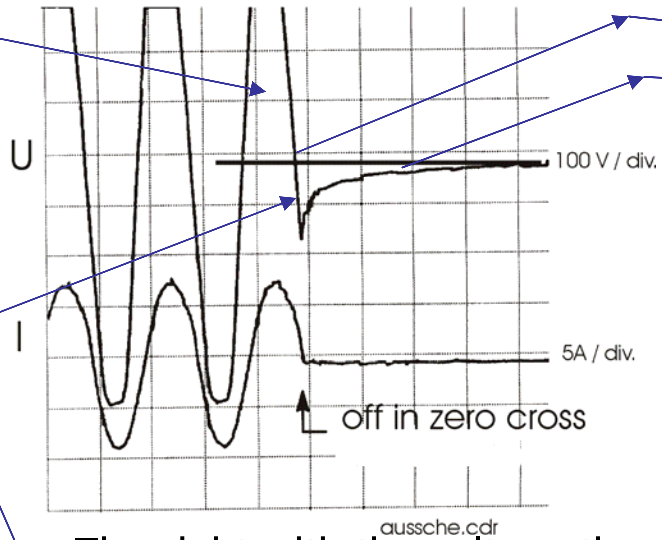
What happens in the transformer iron core-2 :

- **When switching off to the end of an half wave:**
- The last positive Voltage half wave transports the magnetisation B, to the positive return point of the Hysteresic-loop.
- The small negative voltage time area transports the B to the pos. max. residual induction, the max. remnance.
- Following the B stands still and fix in the pos. max. remnance point.

switch off with softstarter

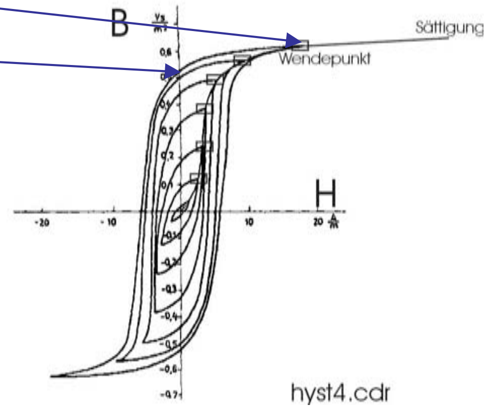
loaded 1kVA transformer switch off with TSE.

No switch off spark occurs.
The mechanical bypass opens earlier like the thyristors.



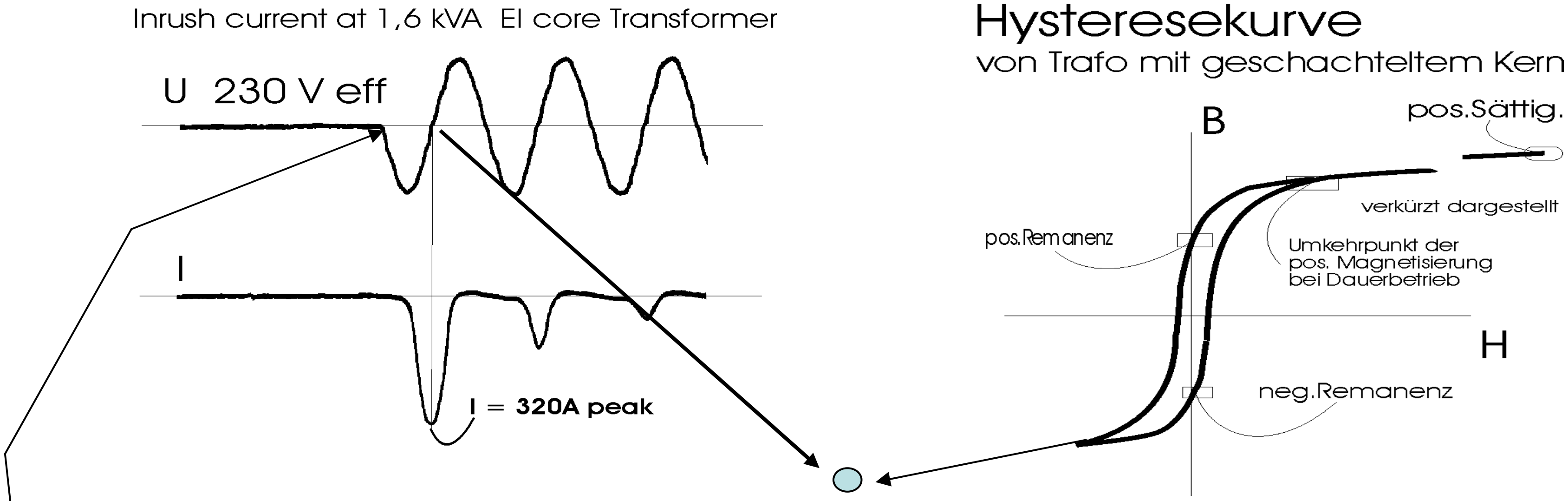
Hysteresefamilie im Eisenkern eines Trafos

je größer die Spannungsamplitude der Trafo-primärwicklung und je niederer die Frequenz desto großer die Hystereseschleife



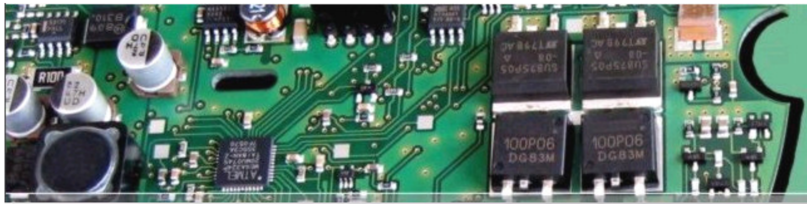
The sight with the voltage time areas helps to easyer under-standing what happens.
Why goes the voltage to negative: Because of the inductive current value, which holds conducting the thyristor until this current is near zero, originate the neg. voltage time area and to spell it like the answer of the transformer when switching off.

Causes of the inrush current, a simple explanation-1:



neg. Saturation to the End of the neg. Voltage Half Wave.

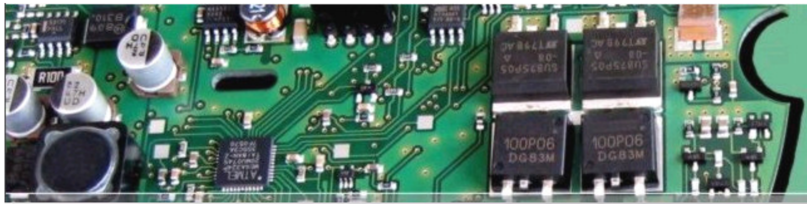
- **Prehistory:** Switch off was to the end of an negative Voltage half Wave. (Opposite to the state in the other example!) Remnance was set therfore on the negative max. remnance point and stays there for longtime.
- Switch on happens now to the begin of the negative voltage halfwave, (In the graphic up left in the top curve.) Now the magnetisiation is brough from the negative remnance point to the negative saturation, reaching his max. to the end of the negative voltage half wave. **That is the worst case switch on, following with the highest Inrush current peak**.



Cause of the Inrush current peak, a simple expanation-2.

- The iron core goes into saturation, when a new voltage half wave does not change the direction of magnetisation in the iron core, and he is furthemore driven in the same direction for magnetisation as before. And if this happens from an high magnetisated Point, with a high B, then the iron goes into saturation.
(Up to a B from 2 Tesla begins the saturation.)
- The remnance is the magnetically memory of the Iron core. He stays longtime there fixed at one point. The high of remnance is depending of the air gap in the transformer iron core. No air gap brings high remnance. A large air gap of any 0,1 mm for an 1kVA Transfo brings a remnance near zero.
- If Switch on a transformer with an half wave in an direction opposite to his switch off half wave, then the inrush is low because the saturation is low, because the core is beeing changed in magnetisiation direction. (But because nowbody knows the amplitude and direction of the remnance, you cannot measure it from outside tof the core, you cannot start directly the transformer in the best case without inrush current peaks. You can only doing that per accident perhaps 1 time inside 10 switch on trials. It´s a bit like russian roulette.)

- While core saturation, only the copper resistance of the primary coil is limiting the current amplitude. It´s than a transformer without iron core in this saturation sate for a short moment.



The cause of the Inrush current-3.

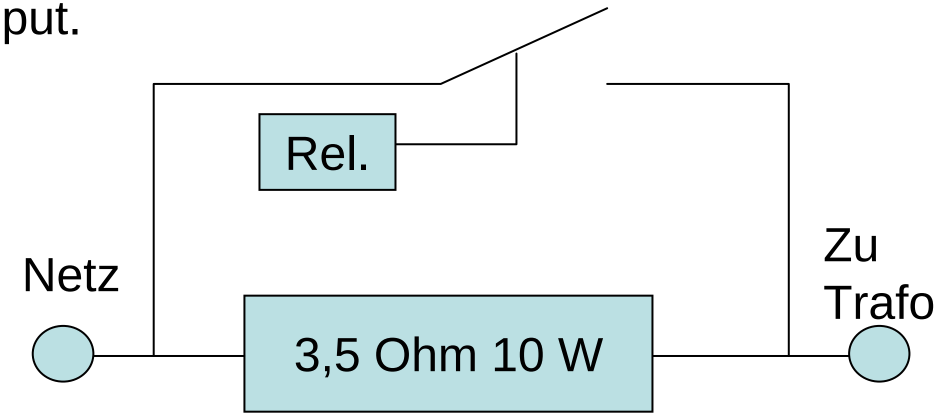
- For that circumstance the current rises to very high amplitudes!
- In the case of iron core saturation, only the primary coil copper resistance added to the Grid line impedance is limiting the current for this half wave of the voltage. In this case the inductive resistance of the transformer is lost.
- The inrush current can rise up to the amplitude of 100 times of the nominal current, at toroidal transformers, in the first half-wave.
- The more the losses of an transformer goes to a minimum, the more higher rises the inrush current.

- (The line impedance is about 0,3 Ohm at a grid for 230V with 16-32 Amps, the transformer primary coil resistance is about. 0,3 Ohm at an 1,6 kVA Transfo, + the plug cable resitance of 0,4 Ohm.) That limits the inrush current up to amplitudes of about 310Apeak in the first half wave after switch on.

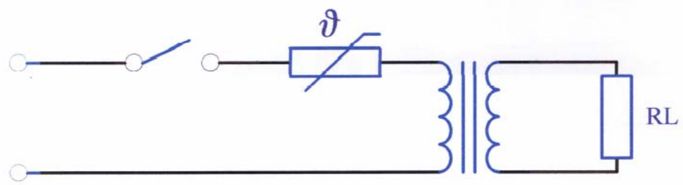
Standard methodes to limit the inrush current, the „Ein-Schaltstrom-Begrenzer“, ESB.

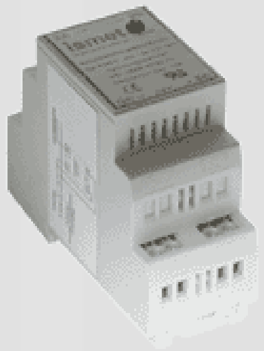
Start with an additionally resistor in the input.

➔ESB with a fix value Resistor and with a bridge over it after a short time.



➔ ESB with an NTC resistor, with or without a delayed bridge.





Typ: ESB-S

Einschaltstrombegrenzer spannungsgesteuert. Die Wirkungsweise beruht auf einem zeitverzögerten Überbrücken des integrierten, fest voreingestellten Begrenzungs-widerstandes. Die Zeitverzögerung ist bei dem Typ ESB-S werksseitig fest eingestellt, (ca. 20-50 msec.). Ausführung im Kunststoff-gehäuse, aufschnappbar auf Tragschiene TS 35.

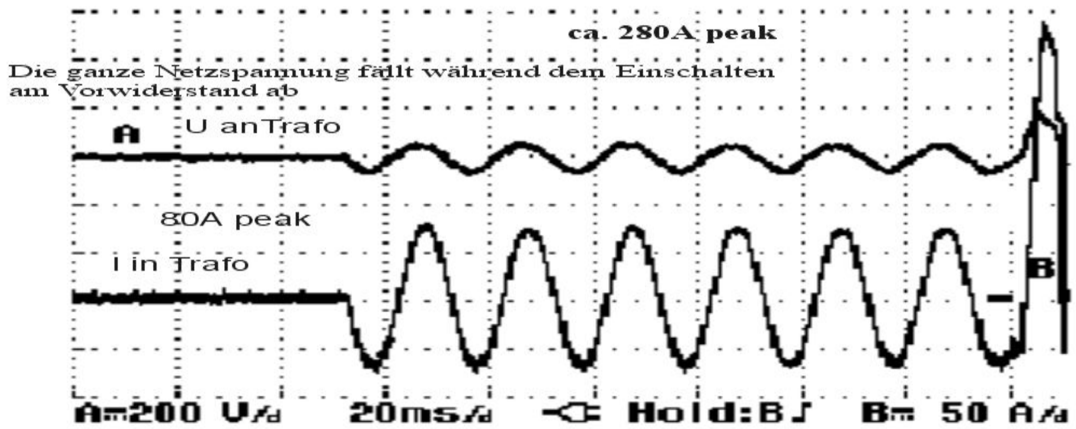
Spannungs- und Leistungsbereiche:

U_{PRI}: 110 - 400 V

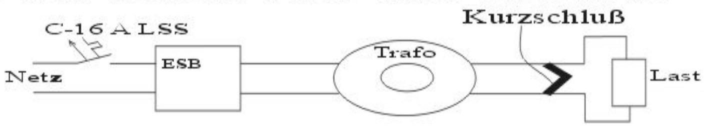
When a standard ESB starts onto a short circuit after the transformer!

Transformatoren schalten. Mit ESB

2 kVA Ringkerntrafo mit Sekundärem Kurzschluß eingeschaltet mit üblichem Einschaltstrombegrenzer, für 230V 16A. Abgesichert mit 16A C-Typ Leitungsschutzschalter, der erst auslöst, wenn das Relais im Einschaltstrombegrenzer den 3,5 Ohm Widerstand brückt..



Das Relais im Einschaltstrombegrenzer wurde bei diesem Schaltversuch beschädigt. Der zusätzlich vorgeschaltete C16A Automat hat nach dem Brücken mit ausgelöst. Das Relais im Einschaltstrombegrenzer hat beim nächsten Einschaltversuch den Widerstand nicht mehr gebrückt, worauf dieser verbrannt ist.

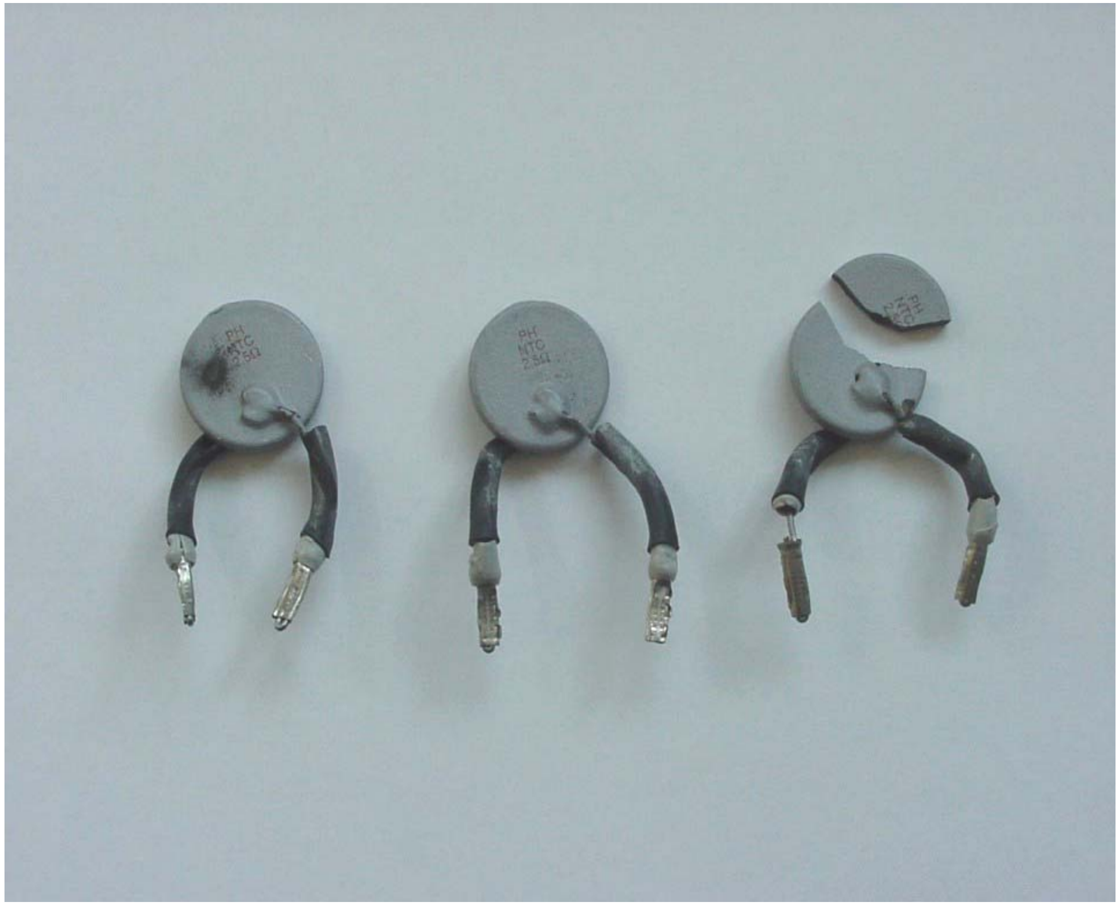


EMEKO, esbkzschl.cdr,

ESB-auf-kurzschl1.cdr

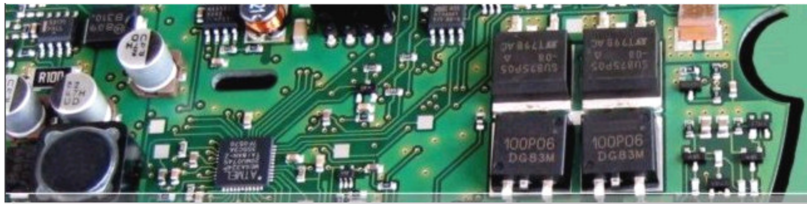
- Curve on top, Voltage on Transfo clamps. Curve bottom, current into transfo.
- Before bridging the resistor, the Losspower at the only **10W** resistance is **12kW**. After bridging him, the current rises up to 300A peak.
- At the next start, the ESB cannot work properly, because the bridge relay is damaged from the Overtemperature of the resistor of the 12KW overload, and cannot bridge him the next time.
- This was truly tested from EMEKO.

NTC- resistors are frequently used for inrush current limiting.



This NTC Resistors are permanently hot when transformer is in the Switch on state.
That´s a cheap but not a good solution. But the most amount of transformers ar softstarted like this, with NTC with a high resistance before start and a low resistance after they are hot.

The picture shows damaged NTC resistors, because of restart after a short time after switch off, and the NTC has been hot and low resistive, and following high currents have destroied them.



Disadvantages from (ESB´s), inrush current limiters.

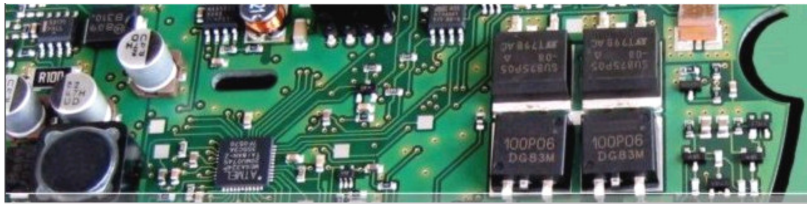
Problems occur if an ESB´s is switching on if the transformer has an overload or a short circuit at his output. The current limiting resistor gets an overtemperature. He can bee destroied or destrois other electronic elements inside the ESB.

Therefore all Inrush current limiters are not shortcircuit proof.

They could only be restarted if his temperature is down, that needs mostly a minimum of 1 minute waiting time between stop and next start.

If an overload state occurs while starting, the current rises to a second and high inrush current peak, because of the bridging of the resistor at an unsynchrounosly time to the grid. Fuse trips than in this case.

All inrush current limiters cannot handle with the the so called voltage dips.. (Because the bridging relays is to slow to open while the dip duration of only an half wave or the NTC resistor cannot cool down fast enough in this case, if the voltage retourns after the short dip.) For electro medical equipments the voltage dip thest is a must.



Resume of the disadvantages of ESB´s.

There are also other limits for ESB´s. Those are:

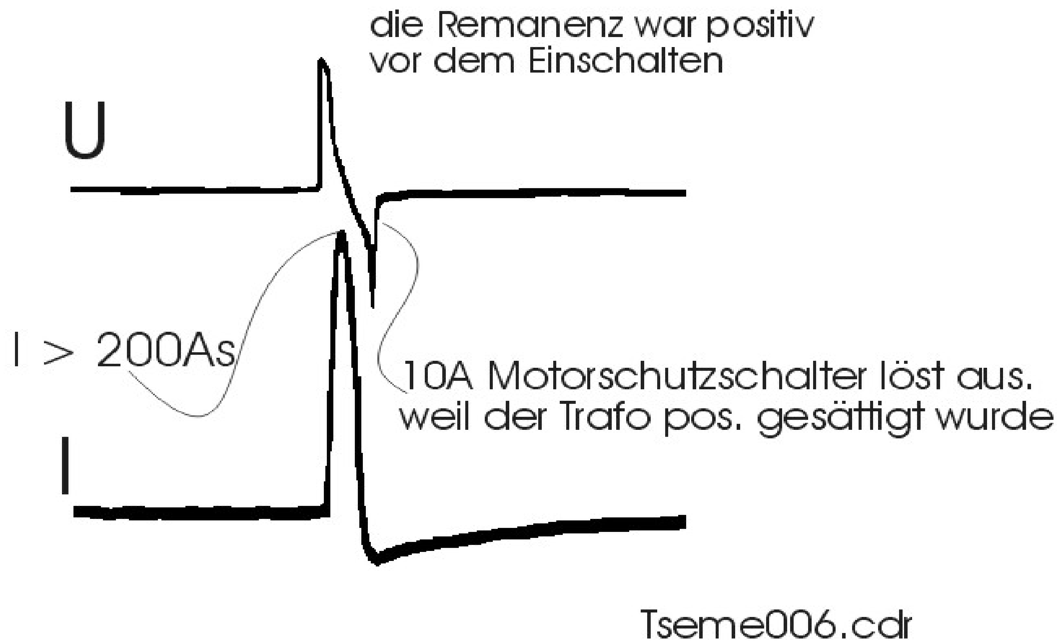
- Frequently switching, start and stop and start again.
- Switching on with overload.
- Switching on onto a short circuit.
- Short time interrupts of the grid voltage. (Voltage Dips.)
- If a transformer must be fuses with his nominal current value on the primary side, current limiting is not enough.
- Life cycles of maximum 20.000 cycles.
- Switch off an on with an voltage hysteresis, against malfunctions from the contactors in a machine control system.

If a peak voltage switching solid state relay starts an Toroidal transformer.

As an deterrend example.

- Although any producers of solid state relays are telling, tor start an transformer the switch on with an peakvoltage switcher ist the best whot you can do.
- But the result is to seen in the graphic at right, if switch on to an toroidal transfo.
- Also in the scientific literature ist often be written, that the peak switching is the best for all kind of transformers.
- Only for a transformers with a big air gap is the peak switching-procedure a convenient solution.

1kVA Ringkerntrafo mit scheitel-schaltendem Halbleiterrelais eingeschaltet.

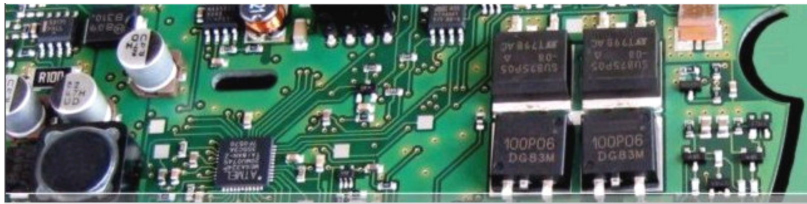


Scheitel-schalter-auf-trafo1.cdr

A TSR is not an inrush current limiter, he avoids the inrush.

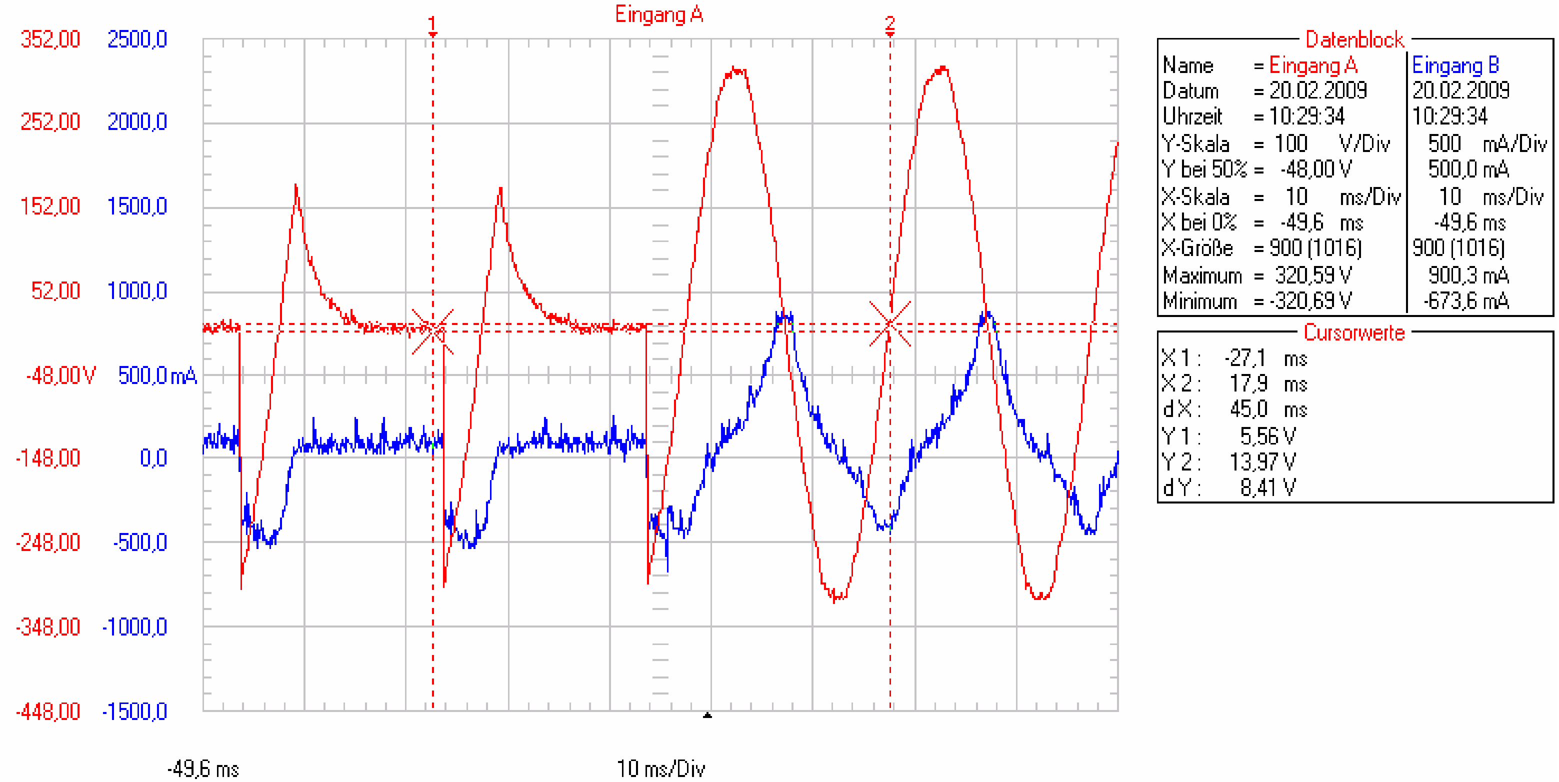
A TSR avoids inrush current peaks because of it´s premagnetising procedure and his full switch on cycle to the physically correct moment..

- To understand all this precisely, you must first read the physically basics for the transformer
- Following is showed, how the TSR does it´s softstart, and where the TSR is used and which advantages then you can have with it.



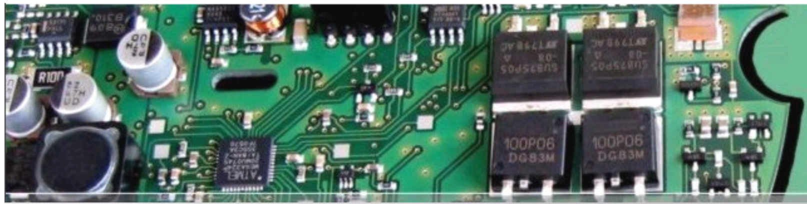
EMEKO and

TSRL Starting procedure with only the flowing of the off-load current at an 1kVA EI-weldedcore transfo if he is in off-load state.

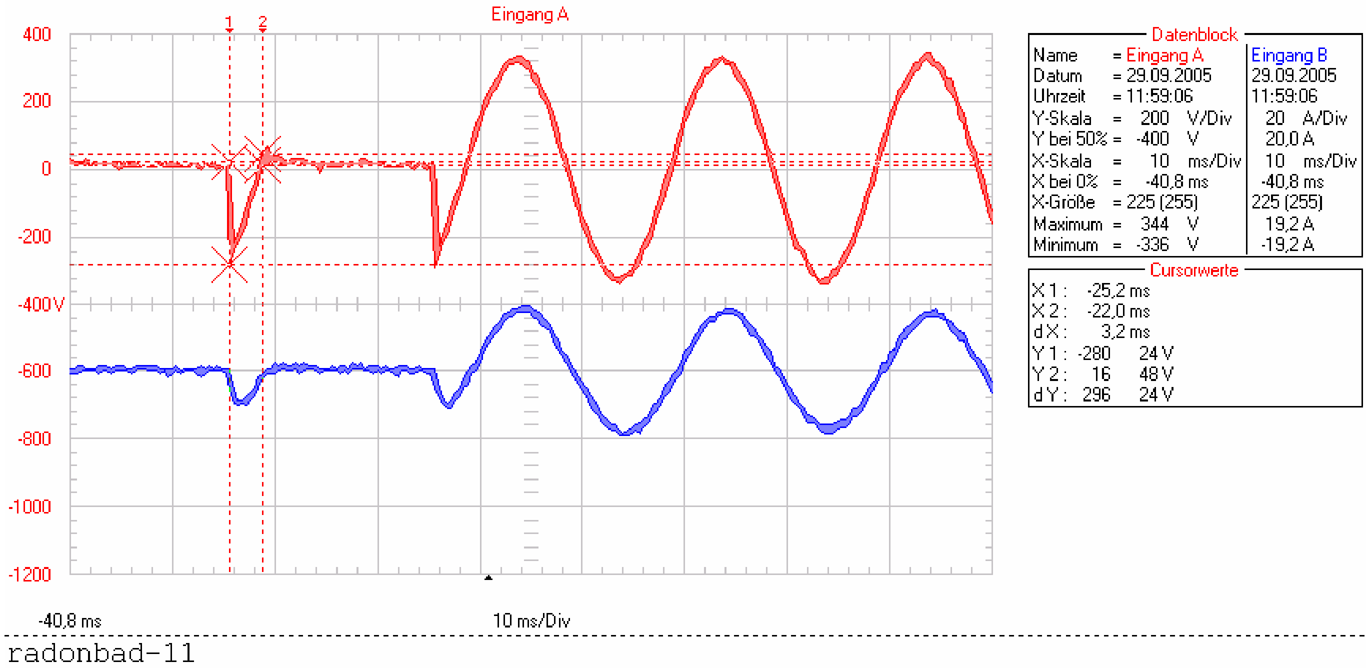


TSRL-EI-1kVA-einschaltenimleerl-14.bmp

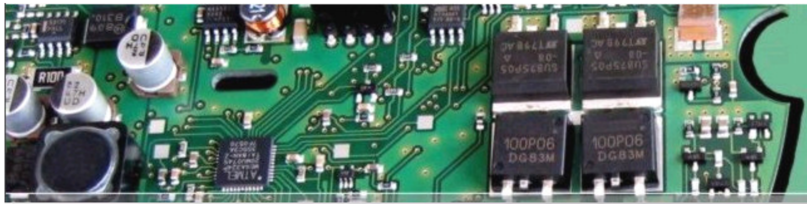
- Red curve: Voltage at transfo. Blue curve: Current into transfo. Scalefactor is 0,5 A / div.. (Directly after full on switching, just the off-load current is flowing, knowing on his typically shape.)
- Can anybody make a better transformer start??



TSRL Start procedure of an 5kVA EI-core transfo with his nominal load.

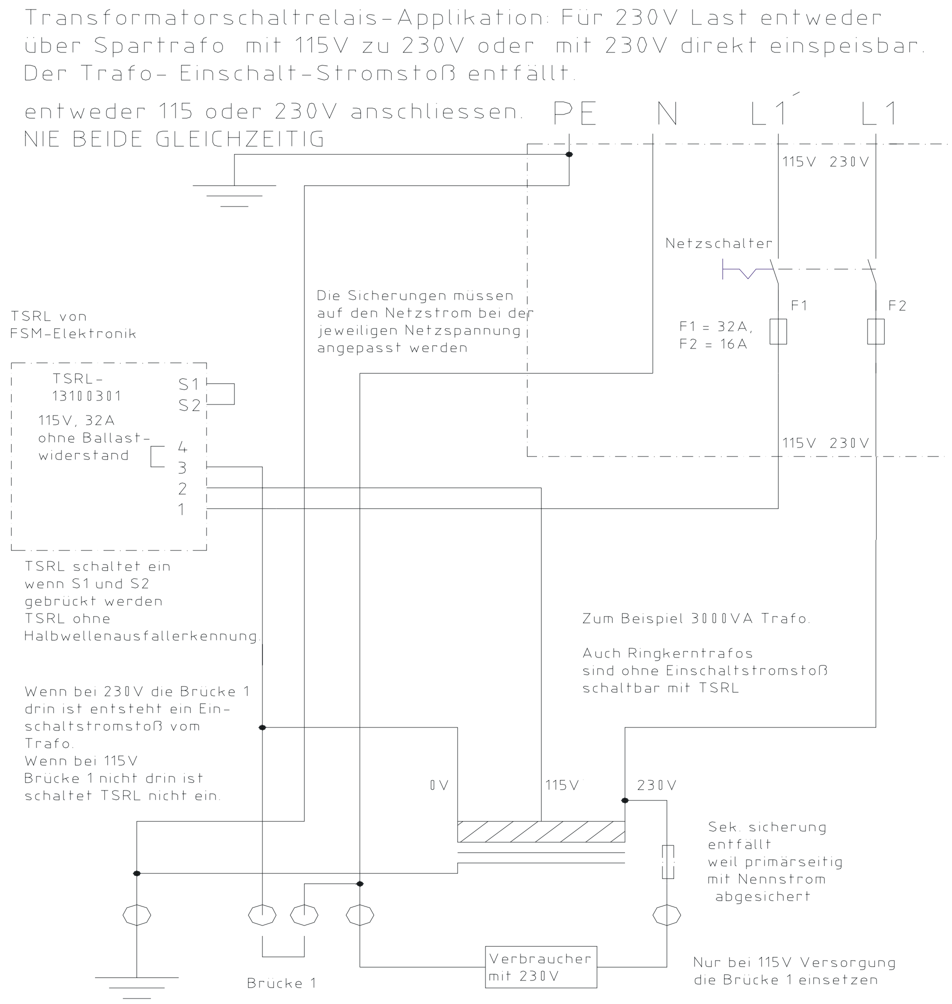


- Red curve, voltage on the transformer clamps. Blue curve: current into transformer. Scale factor is 20A per div.
- No inductive current peaks are seen only the resistive current from the load.
- No difference in Switch on behaviour between noload and load at the same adjusting of the high and width of the voltage areas to premagnetise the transformer correct, here 3,2 msec. width.

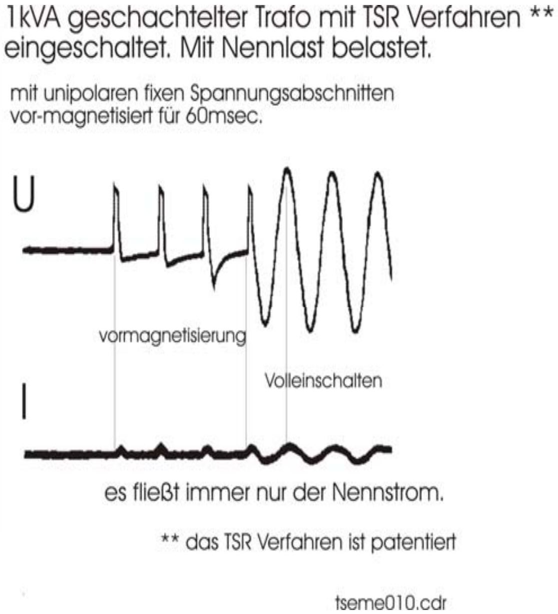


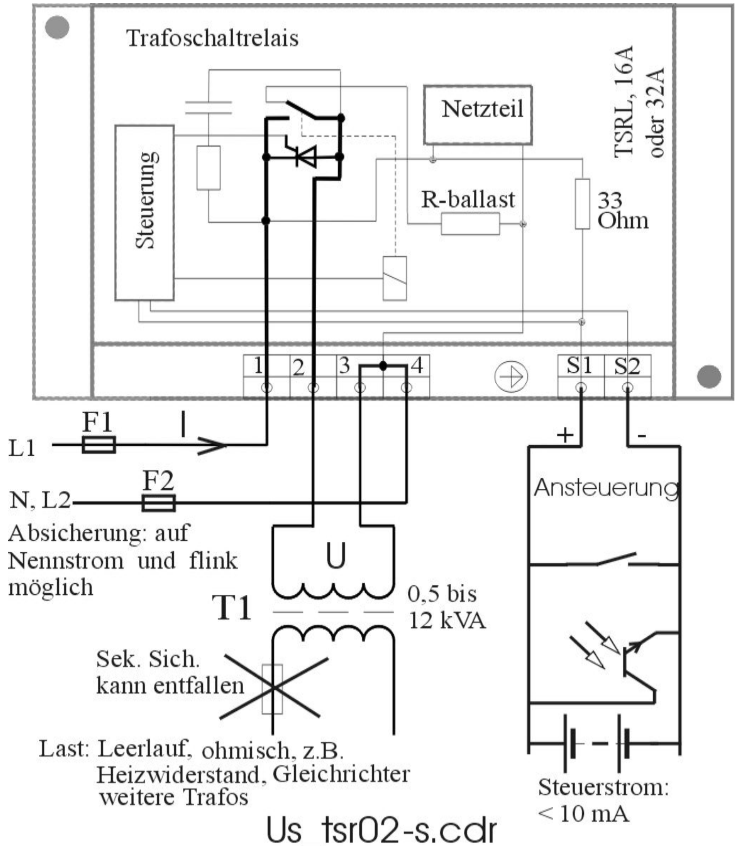
One from „about 1000“ different Applications of the TSRL.

- For a machine to export from one customer, the Adapting transformer for 115V to 230V stays for everytime in the Machine, also if the tranformer is not need.
- With a „Bridge 1“ over 2 clamps, in conjunction with the different connectors for 115V or 230V, the Function of transformer is selected or not.
- The TSR allows the fusing of the nominal vlue of the primary current and avoid the trip of the Building fuse at the machine customer.



The Transformer-Switching-Relay, Function und drawing scheme.

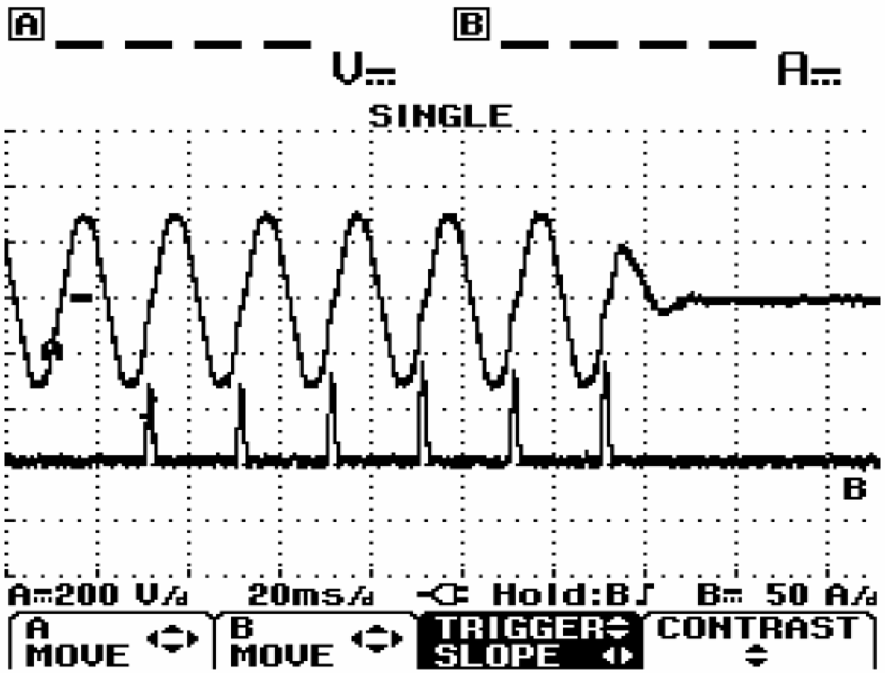




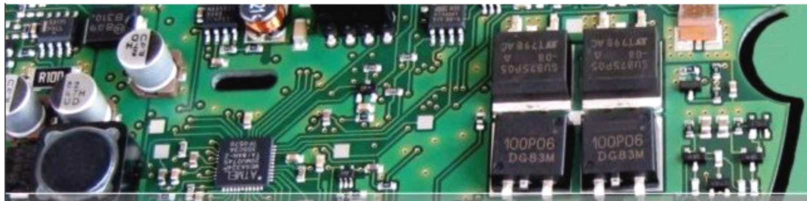
The TSRL, as an bridged solid state relay, correspond EN60947-4-3, is switching in a soft manner, without a Pre-Resistor, and therefore load **un**-depending. The premagnetissing cycle transports with small unipolar voltage time areas the Magnetisation B, to the right point to switch on in a physically correct manner.

The TSRL is short ciurcuit proof under normally* circumstances.-1.

- The graphic at right shows a switch on cycle from TSRL onto a short circuit 2kVA toroidal transformer (The transformer output has a short circuit.)
- Upper curve from the line voltage, after the fuse, shows his tripping.
- Lower curve shows the flowing current into the transformer.
- The fuse, an R10A LS Line protector switch is tripping after the 6. premagn. Voltage time area.
- The Thyristor can conduct 500A for 10 msec. and gets here, at the only 80A high and only 2 msec. width peaks naturally no damaging.
- If a higher valued fuse not trip while the premagnetisiation, the he trips shurely at switching on, seen in the next foil 21.
- * Normally circumstances are a 230V or 400V grid with max. 32A fuses with corresponding cable area sizes.



2kVA Rktr.mit sek Kurzschluß einge-
schaltet. I in Trafo 80A peak, (Ausl
ösg. bei 60A peak.) mit R10A B-Typ
Leitungssch.sch. abgesichert,
schon beim vormagn.ausgelöst. A= U
nach Sicherung.
17.11.98 Emeko
Ing.Büro D79114 Freiburg
tsf103.fvf

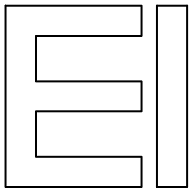


Hysteresic loop of a transfo with a welded core (EI core with considerable air gap)

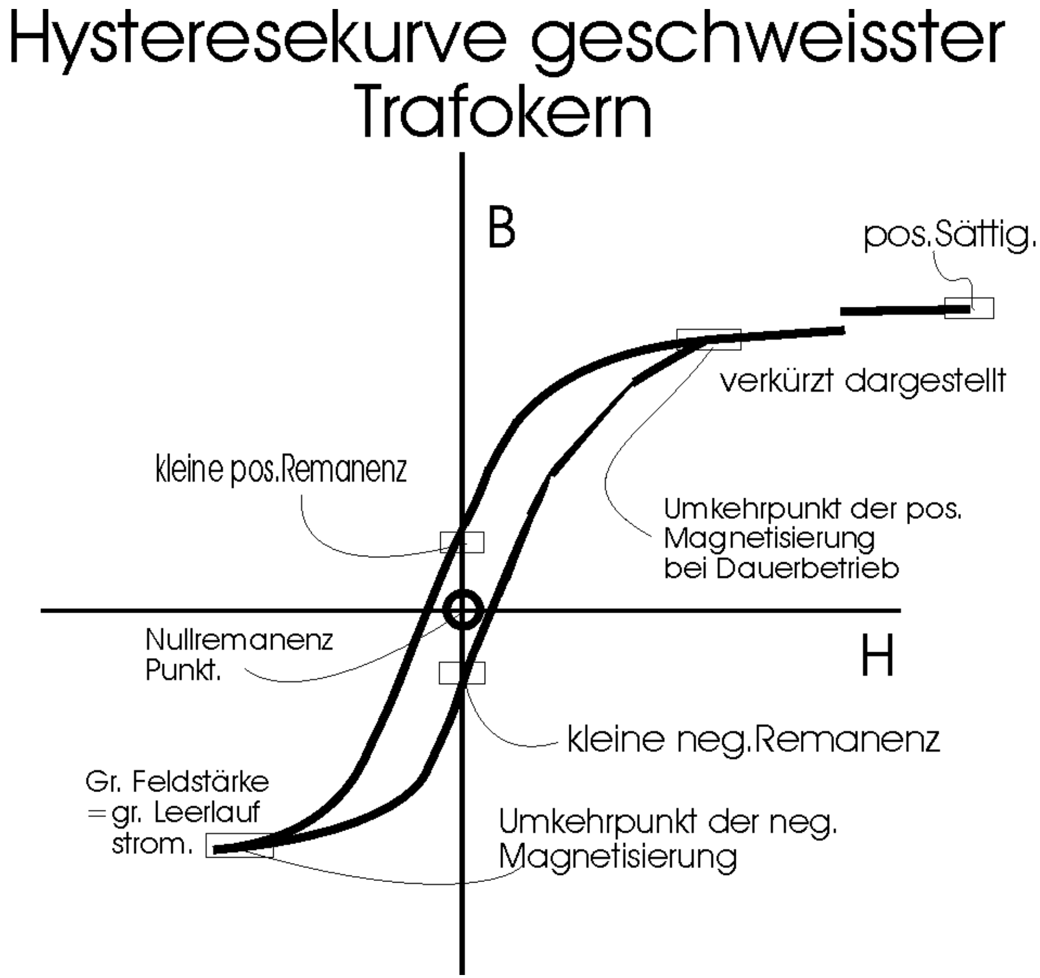
➔Through the considerable Air gap, the hysteresic loop is incline to the right. The max. remnance point. –point of intersection of the hysteresic loop with the axe B,- has a considerable lower value than the max. B. (Also the off-load current at the turning point of the loop has a higher value. The I off-load is proportional to H.)

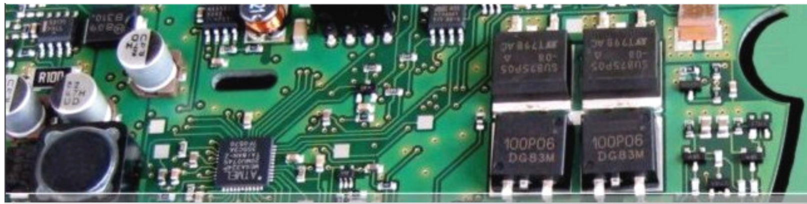
➔**Only such types of transfos are to be switch on with an peak point switching solid state relay. All the other types not, see next foils..**

➔In the literature is unfortunately to read, that all kind of transfos are at the best to be switch on with the peak-point-switchers.



(EI core transfo)

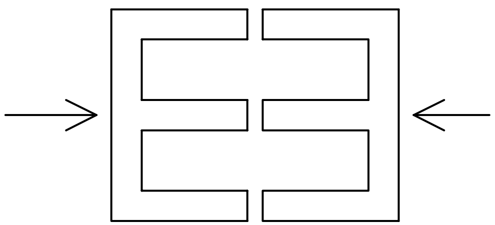




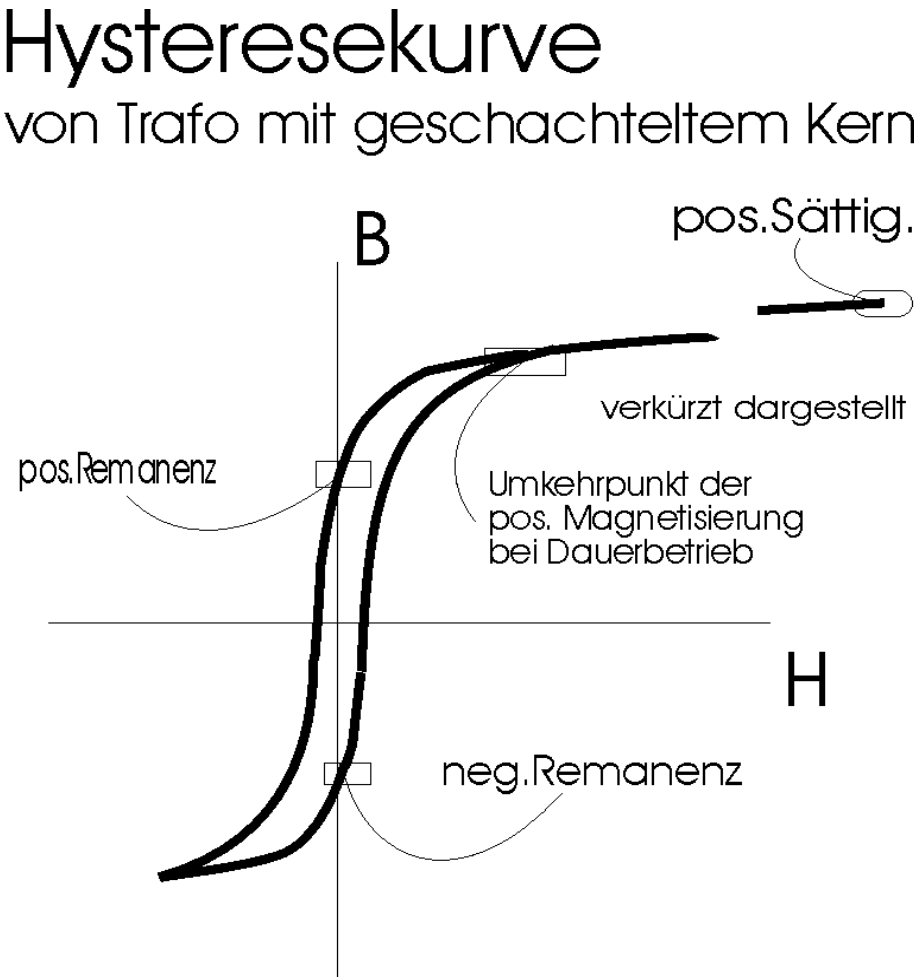
Hysteresic loop of a transfo with a stacked core (EE core with less air gap)

➔ The hysteresic loop runs more vertically than before at the tranfo with the considerable air gap.
The max. remnance ist higher, the off-load current and the H is lower.
Depending of the Start point to switch on of the loop, relative to the remnance, rises a more or less higher Inrush current.

Stacked core



Stacked Laminates shifted with alternating sides.

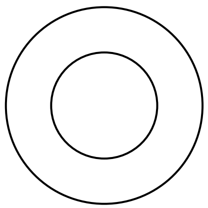


Hysteresic loop of a toroidal core transformer (without air gap.)

➔The max. remnance is nearly as high like the nominal B at the turning points of the loop.

➔The off-load current is very low, because the H at the turning points is very low. (About 100 times lower than before at the EI core.) Dimension of H: [A / cm]. In this case cm of the air gap.

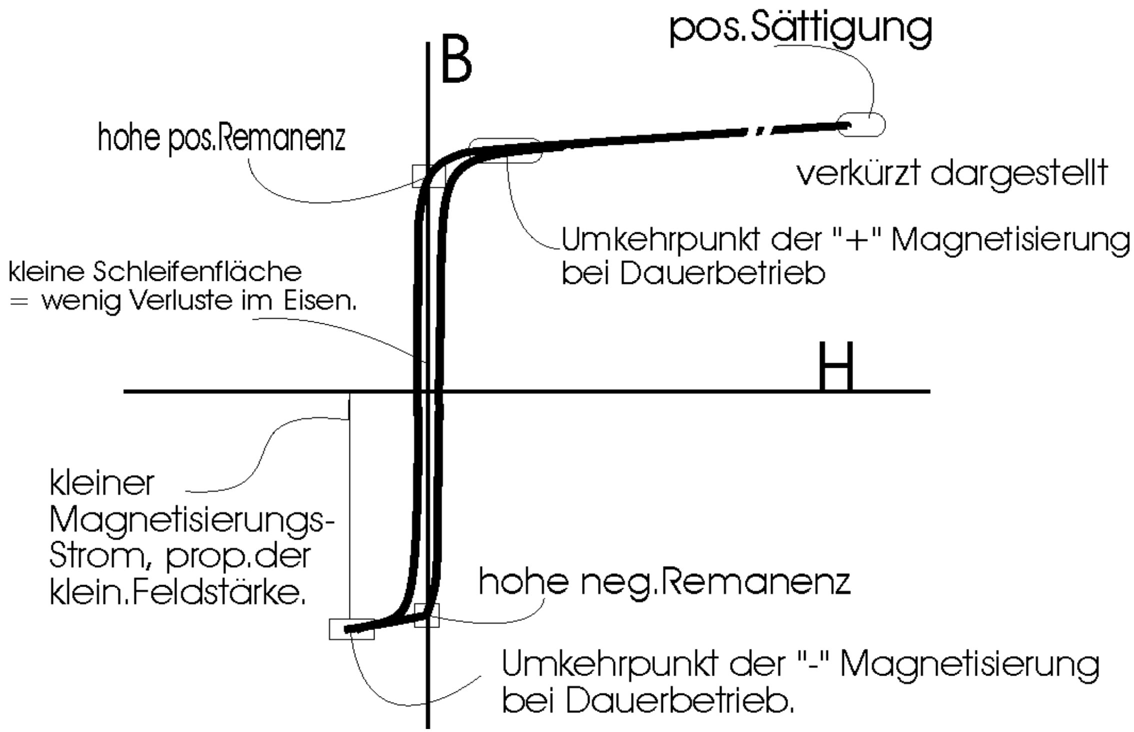
➔Such transfos has a big inrush current peak, but low losses.



Toroidal core

Hysteresekurve

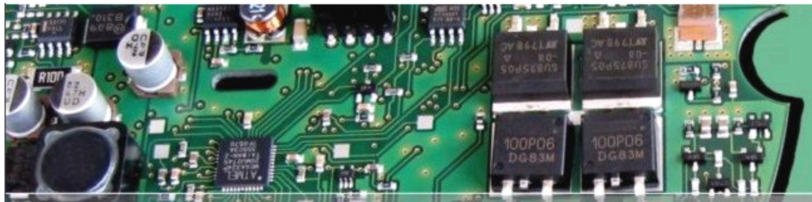
bei Ringkern-Trafos
luftspaltfrei deshalb hohe Remanenz



How the TSR can deal with all the differnt Types of transformers?

- How can the TSR all kind of transfos switch on in the same inrushless manner?
- Very simple, The broad, the height and at the same time the count of the premagnetisiation pulses are to be adjusted with an trim pot onto the board of the TSR.

- (FSM can deliver also TSR without a trim pot, with per Software fix adjusted Pulses, for a predefined transfo type.)



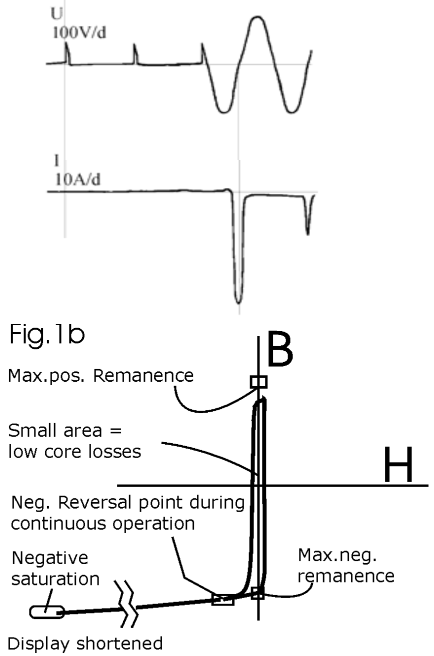
EMEKO and FSM

Adjusting samples with a TSR.

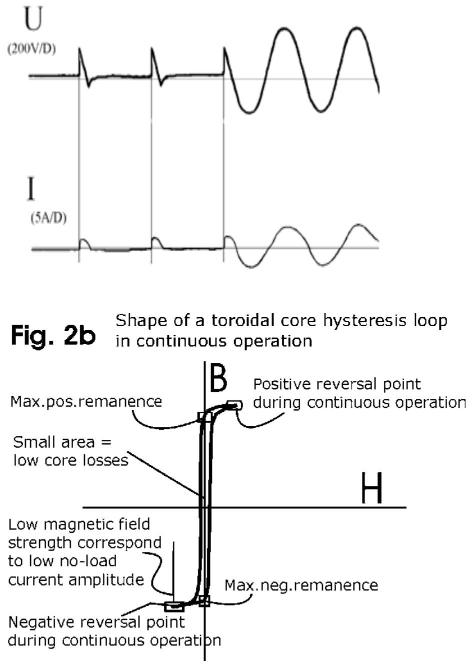
Sample for an Toroidal core Transfo.

Like on can see, the strengh of the Premagnetising effect depends of the amount of the voltage-time-areas.

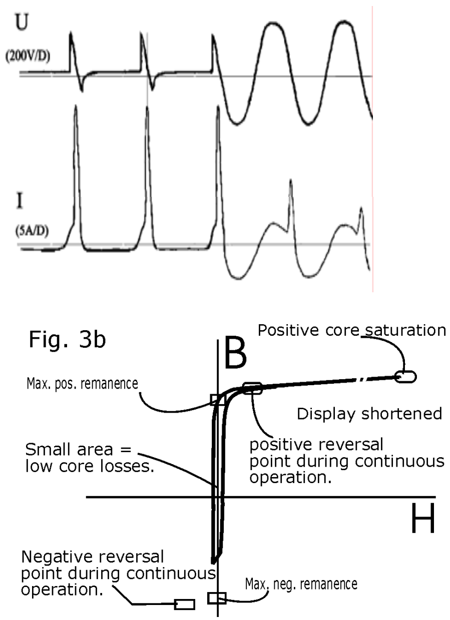
The current-answer of the transfo, tells us what´s happen inside the core.



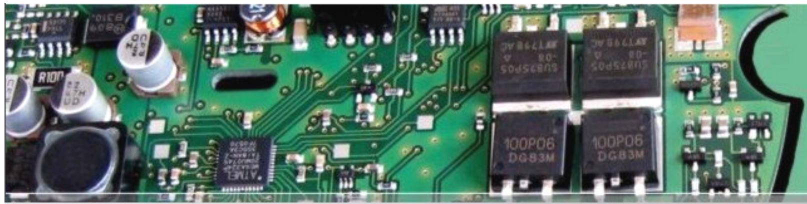
To weak premagnetised.
-40A peak at
Full switch on
in no load case.
The Not good adj.case.



Correct premagnetised.
No current peak I at fully switch on.
Trim pot on 8 o clock 30.
Adjusting is not load depending.



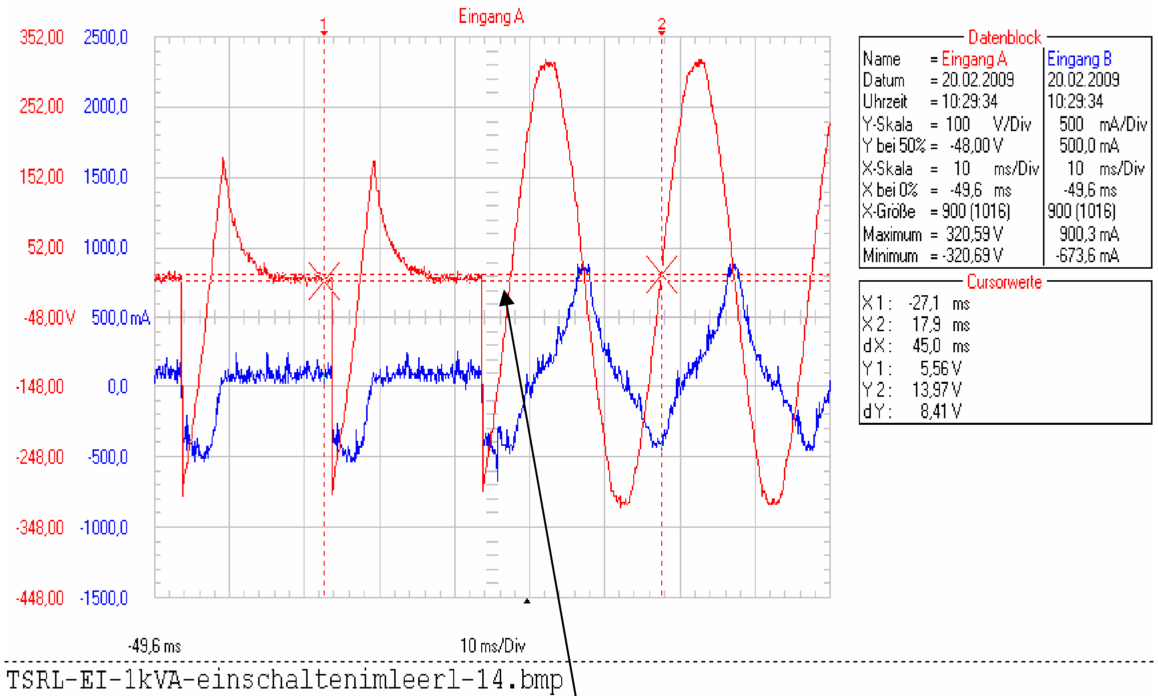
To strong premagnetised.
+25A current needles at fully switch on.
A harmless case.
Trim pot on 9 o clock 30.



EMEKO and FSM

TSR-Switch on samples with different transformer types-2.

- The unloaded 1 kva EI-core-Transfo with a stacked core, with a small air gap, needs some voltage Pulses with 3 msec. broadness.
- 8 pulses ar needed, because of the high starting max. remnance, to transport the B to the opposite point.
- **The trim pot is adjusted on 13 o clock.**



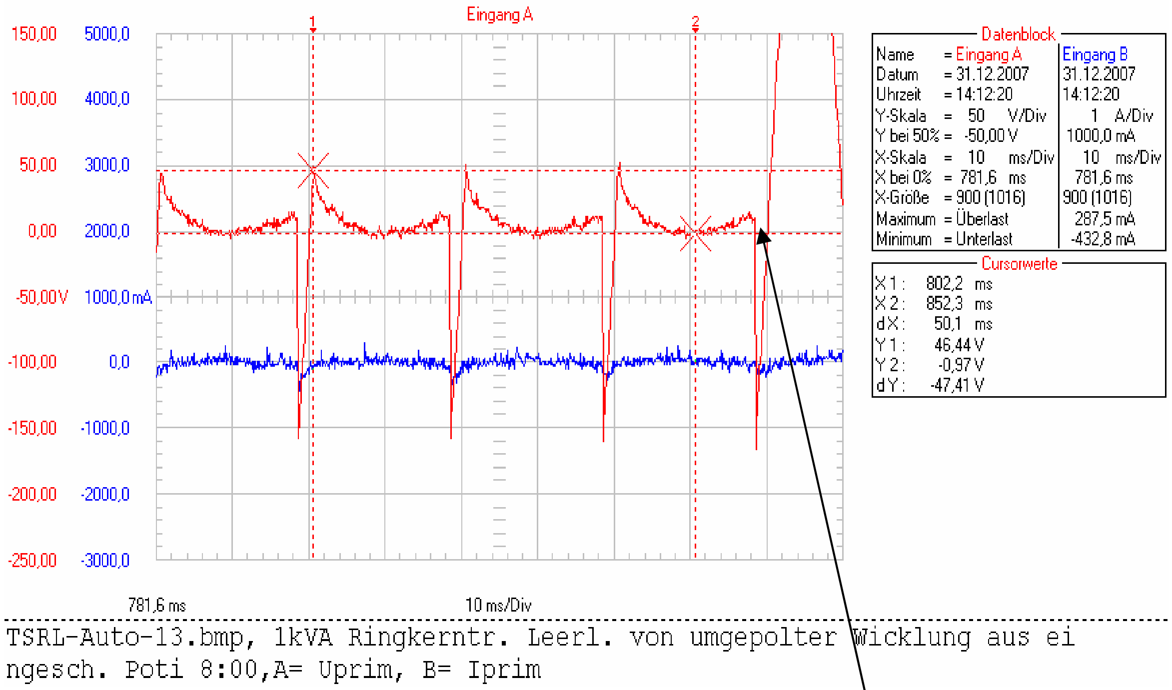
Switch on in the best case
with only the off-load current

Here is the full switch on point.
Red is the voltage, blue is the current.

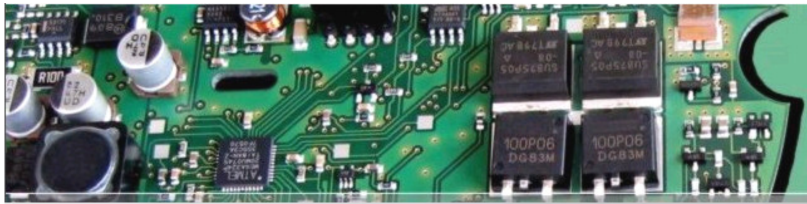
TSR-Switch on samples with different transformer types-3.

- The unloaded 1kva toroidal core transfo, need voltage pulses of only 1,8 msec. broadness.

- 40 Pulses ar needed, **The Trimmer can be adjusted on 8 o clock until- 8 o clock 30.**



Here is the full switch on point.
Red is the voltage, blue is the current.



Advantages from an Toroidal core Transfo:

➔ The best Transfo can be an toroidal core transfo, because he can built up with very low losses with representative costs.

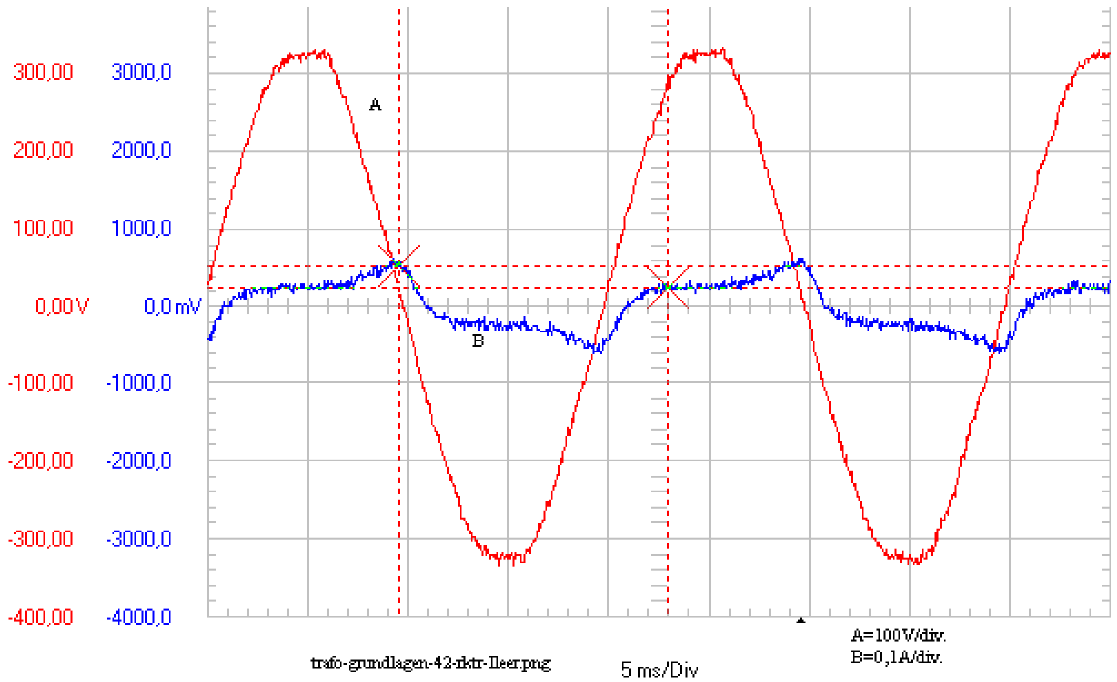
- He has the lowest iron core losses, to seen at the very low off-load current, the lowest weight and a very low stray field. He has a big sized window for the windings , and following you can wrap it with oversized wire diameters and that leads to low copper losses.

- But his origin disadvantage, the high inrush current, can be totally avoided with a TSR. And you must not spend an higher primary winding resistor, if you wrap a smaller diameter wire, or a reduces B in the core to limit the inrush. His off-load losses are up to 50 times lower than at a stacked core transfo.

- Because the higher material costs, are rising the advantages oft the toroidal transfo, because he needs the fewest of all material in relation to power. kg / watt.

No-load current of a toroidal core transfo with 1 kva.

- The shape of the current decay over time is totally other as from an EI-core transfo. (Showed in the next foil.)
- The nearly horizontal course of the current in the middle of the voltage half wave and a much lower amplitude are flashy.
- *Compare the next foil, who shows the off-load current of an EI core transfo.*

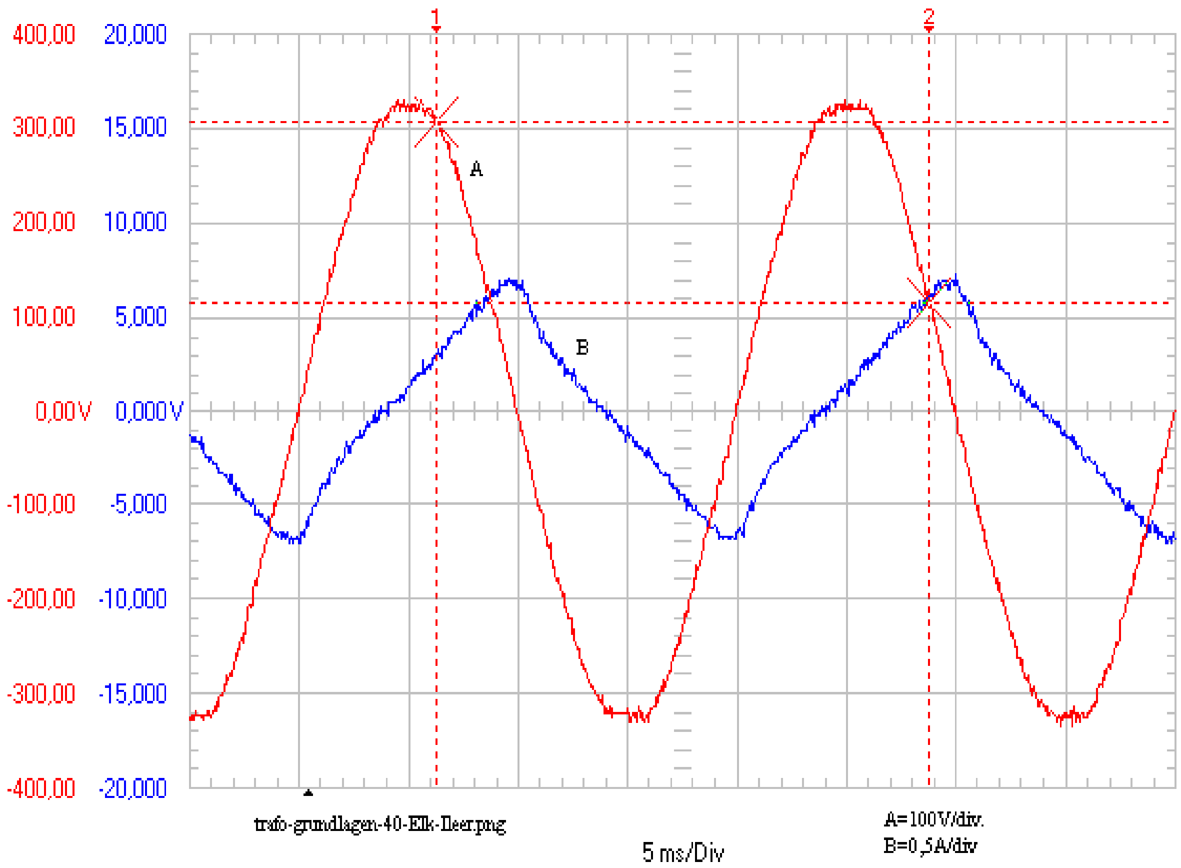


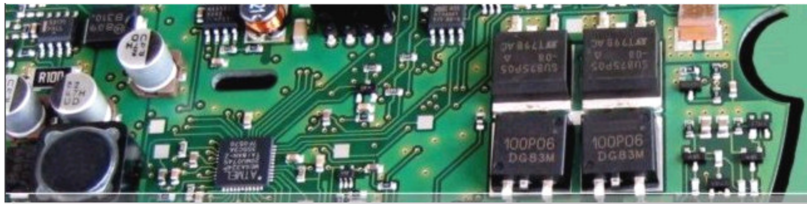
You cannot say, that the off-load current, blue curve, has a lag of 90 degr. to the voltage. In the middle of voltage curve he is even in phase.
In the most of literaturs is the off-load current showed as a sinusodial shape who has a lag of 90 degr. to the voltage, and that is a fault.

To comparison: Off-load current of an 1kVA EI-core transfo.

- Much higher and triangle shaped course of the current, because of the considerable air gap into the core.
- The most of the amount of Field strenght H and therfore the off-load current is needed to magnetizes the air gap. (linarly rising.)

- Here has the off-load current a nearly 90 degr. lag to the voltage. But he has not a sinusoidal shape.



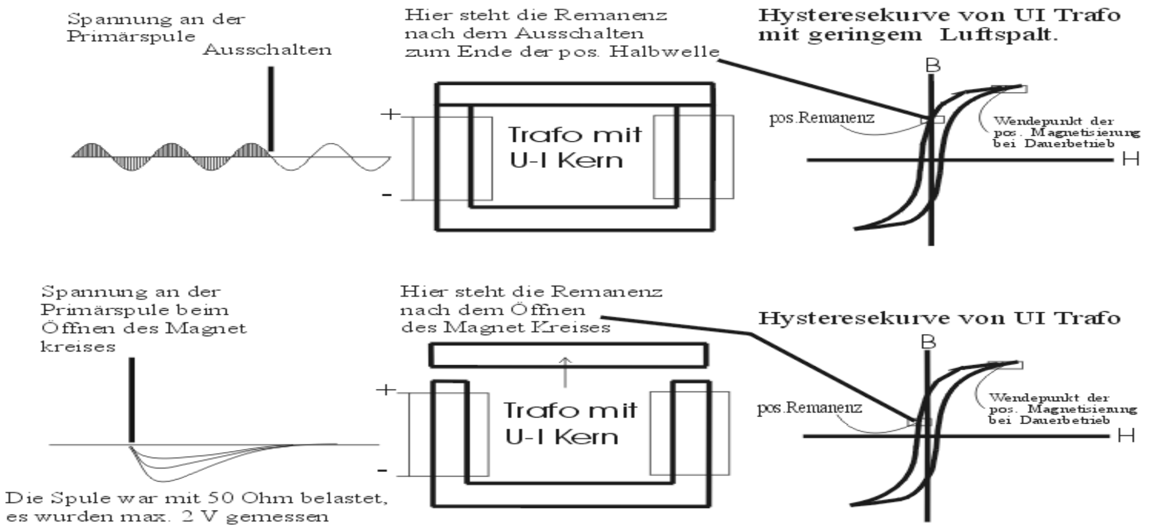


What is Remnance? An Expiriment to learn.

Load up and fixing of the magnetisation trough switch off from an continuing AC Voltage to the end of the voltage time area from a pos. half wave. B runs to the + max. Remnance point and staying still.

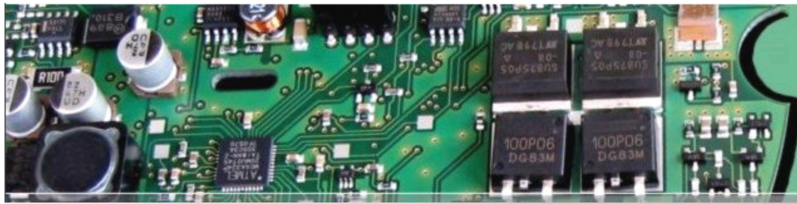
Discharge of the magnetisation trough the lift up of the core I-Leg for any counts.
Look onto the decay of the B on the hysteresic loop, he is sinking deeper and deeper. Also the back sended voltage.

Versuchsbeschreibung zum Nachweis der Remanenz im Trafo Eisenkern



Beim Öffnen des Magnetkreises durch schnelles abheben des I-Schenkels, entsteht eine Selbstinduktions-Spannung an der Primär und Sekundärspule. Dieser Spannungsimpuls entsteht durch den Abbau der Remanenz. Die Remanenz kann sich nur im geschlossenen Magnetkreis halten.
Im entstehenden Luftspalt reicht die magnetische Spannung nur noch, um einen wesentlich kleineren Magnetfluß aufrecht zu erhalten.
Nach einem erneuten Schliessen bleibt die Remanenz auf diesem niedrigeren Niveau stehen. Die anfangs hohe Remanenz wurde durch das Öffnen des Magnetkreises abgebaut.
Die Remanenz verkörpert eine im Magnetkreis gespeicherte Energie, die beim Entladen frei wird, wie an der Erzeugung des Spannungsimpulses sichtbar wird. Wird der Magnetkreis mehrmals wieder geschlossen und geöffnet, dann wird der Spannungspuls kleiner, verschwindet aber nicht ganz, weil eine geringe Remanenz erhalten bleibt..

Remanenz-vers-1.cdr



Iron Core losses.

The core losses, also called no-load losses, are as much higher, as the Hysteresic loop broader an higher is. (Losses are proportional to the Area inside the curve.) The losses have not only to do with the hight of the Induction B. They develope from the magnetically resistances inside the Core Material. This resistance is into EI cores higher than in wrapped cores, because of the non flow aligned core foils. The magnetic flow must overcome the hihger resistance in 2 of 4 core legs. (Lateral to the best flow direction in the core foils, is the magnetical resistance higher and the suturation occurs at lower induction B more early.)

Saturated zones inside the core are like an additional little air gap.

See datasheet from iron core foils.

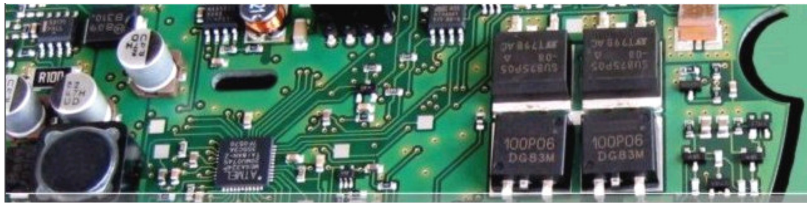
Iron Core Saturation

- The magnetical flow density, B, the so called magnetisation, cannot rise higher than over the limit of the saturation. (2 Tesla max.) After the begin of the saturation the magnetisation can only rise higher for a small amount. Dont care of the amount of driving voltage-time-area at the primary windings. If the driving voltage-time-area drives the core although at the begin of an voltage curve into saturation, then the current will be only limited until to the end of the voltage curve in this half wave from the resistant of the copper wire from the driving coil. And he is very low for a good transformer.
- (All the Weissche districts inside the material are aligned then.)

How does produce the transfo the secondary voltage and the counter EMF-1?

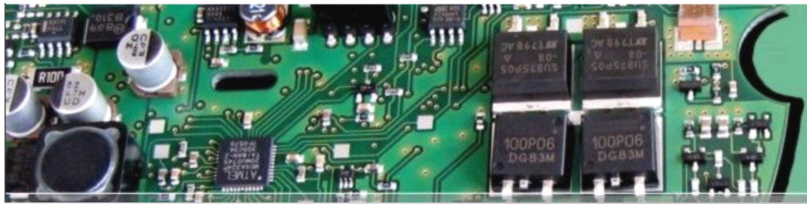
- The influence of the primary voltage produce the secondary voltage through induction in the coils. Induction happens through change of the Magnetically flow Phi, precisely through changing of the flow dense B. Dimension: [V * sec. / area]

- The Magnetflow Phi (t)= Integral of Uind(t) * delta t + C. Dimension: [V * sec.]
- The magnetflow Phi is rising higher proportional to the influence of applicated voltage time area, while the iron core is not saturated.



How does produce the transfo the secondary voltage and the counter EMF-2?

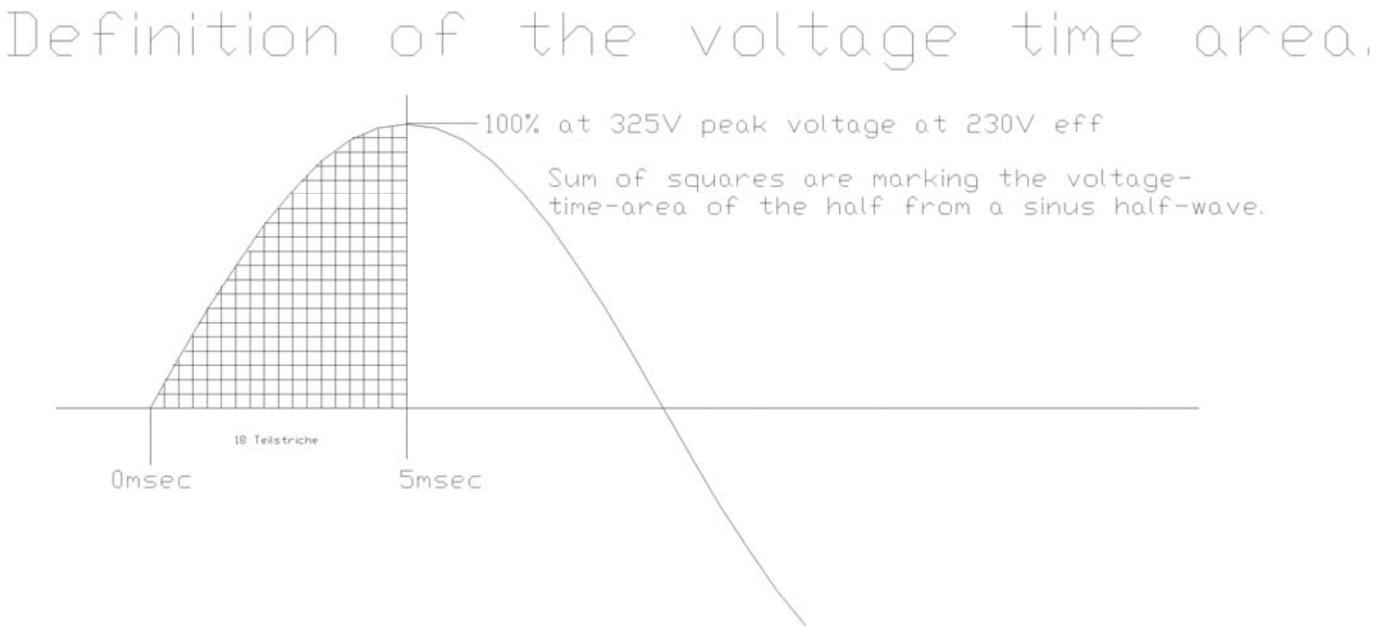
- Phi = Upr / N * F, or Phi = U * d t / N.
- Delta Phi *1= 0,225 * U / F * N, for a sinusodial shaped voltage. [V sec.]
  *1 for the full Induction amplitude from –B to +B. (then normally 3,2 Tesla.)
- Phi reaches his Maximum for that to the end from each voltage half wave.
- Voltage V pro Winding = delta Phi / delta time.
  Dimension: [V * sec. / sec. = V] Induktionslaw.)
- The amount of the Magnetflow change and the amount of the applicated voltage time area, wich is the reason of the magnetflow change, are linked together.
- That has found Sir Michael Faraday in the past. He tells Voltage-push to that. (Both parameters has also the same Dimension: **V * sec**..)



What is a „voltage time area“??

- To understand what´s happen if a transformer if he is switched on per accident, and to understand the softstart procedure of the TSR, is the sight with voltage time areas very helpfull and also simple. (Less articles are to found in the literature. Most of them to calculate the dimensions for switch-mode-supply-transformers and not for 50HZ transformers, but the physic is the same.)
- The dimenson of the magnetflow Phi is [Vs], of B is Vsec./cm*cm.
- The magnetflow Phi is also = B * A, (A = core area, B = flow density.)
- Phi and also B are permanently changed in the core of the transfo and in the coils and at the same time originates the secondary voltage V = delta Phi / delta time.
- Phi is reaching his Maximum value to the end of each voltage half wave. [Dimension = V * Sec.] and naturally to the end of the hysteresic loop.
- Following is Phi or B influenced from the product of momentual voltage times Timepeace, [Volt times Seconds.]
  See following foils.

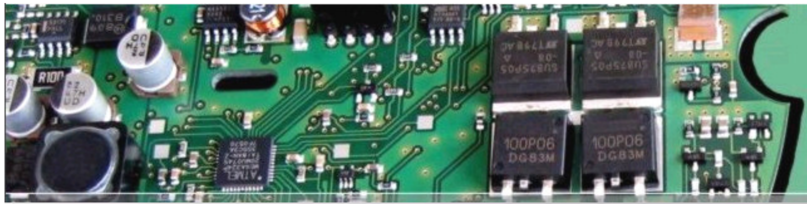
One more time the sample for the voltage time area definition.



- The sum of the small squares marks the voltage-time-area from the half of a sinusodial voltage half wave is 1 voltseconds. But also each other part area on each position position of the time axe of the curve is also a voltage-time-area, greater or smaller.
- The voltage-time-area of a sinusodial voltage half wave at 230V und 50 Hz has the amount of about 2,0 Voltseconds.

Magnetising current or Voltage-time-area-1?

Most Teaching books are saying until yet:
The current trough the coil does magnetise the iron core and produces the voltage at the coil. That´s ok for the sight to the EMF into the primary coil and for the secondary coil, but what´s with the voltage applyed to the primary coil? (The current is not present in the formulas for the voltage generating, see the foils above, there are only voltseconds into!!) The current is responsible for the magneticfield, and that´s obvious for an Electromagnet who is feeded with dc voltage, but he build also the magnetic field inside of the transformers core. But the change in field strenght is much lower than the change of the B, particularly at a toroidal transfo.
The induction of a voltage is also better to understand through the change of the magnetic flow delta Phi. And therfore the current is not responsible. On can say the offload current is the answer of the transfo. The detour via the magnetisation current is not needed. The current is depending from the shape of the hysteresic loop and she is depending of the core shape, but the voltage time area is always the same.
Why is the off-load-current for more than factor 50 different, at different transformers with the same power size,? (He is only depending from the air gap in the core and the core losses.) The voltage and the frequency, (the voltage-time-area) has the same value at both different types of transformers, simply because they are feeded with the same grid voltage!
To evaluate the voltage depending effect at transformers, suit the voltage-time-area much better than the current. The current is depending of the transformer shape and the load, the voltage-time-area does not change, he is the same for all types of transformers and loads. Much students could have less problems to understand the transformers physic, if they would use the sight with voltage-time-areas.



Magnetising current or Voltage-time-area-2?

The understanding of the things happens in the transformer is much more easy if on says:
The current into the off-load transformer is **only** the **Answer** from the transformer to the primaryside applied changing of the voltage-time-areas.
(Not reversible is the voltage the answer to the off-load current changes.)

The off-load current is only depending from the core shape an Size, the air gap and core losses and also from the material of the core.

On should better say for that: Not the current is feeding the change of the magnetisation, driving the B along the hysteresic loop, but rather the voltage applyed at the transformer, transports together with the appealing time the magnetisation B in the core along the hysteresic loop. But the current is needed to built up the magnetic field.
The off-load current shows only that´s what happens inside the core.

Rule of Induction-3

For an electro technician it is correct to see the voltage as the cause for an current flow, not opposite.

The current is the result of the effect of the voltage on a resistance, will say, the voltage drives the current via the wire trough the load.
Without a voltage flows no current.

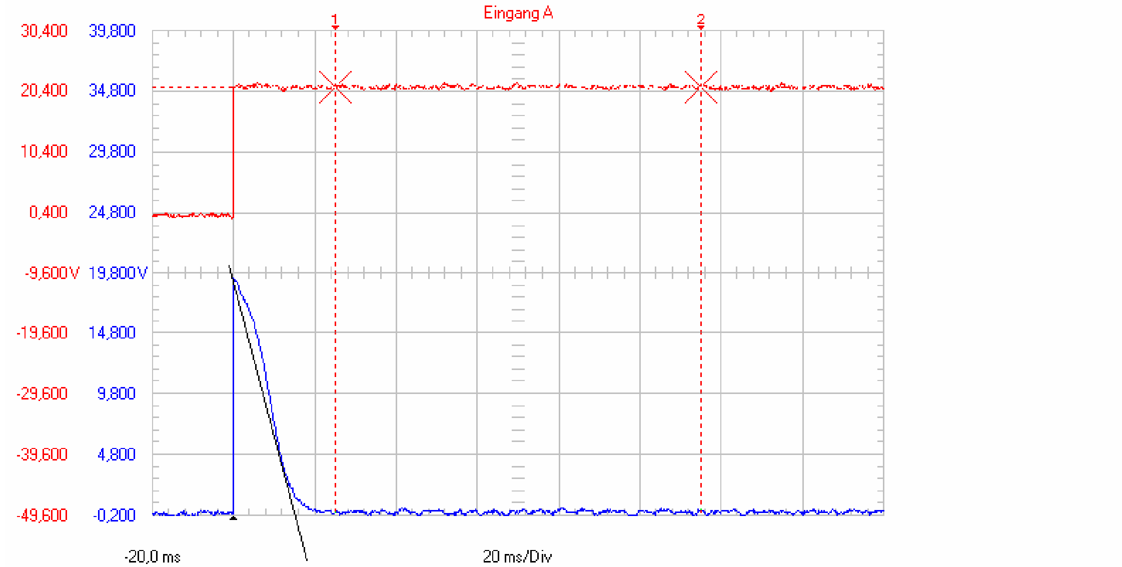
For transformers for switch mode power supplys is the calculation with voltage-time-areas a standard since a long time.

On the following foils is demonstrated with voltage and off-load current measurings at different transformes, how the effect of voltage-time-areas is.

Induction happens only as long as the transformer core is not saturated 1.

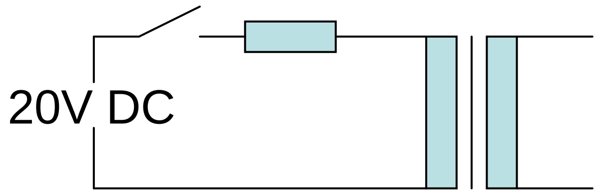
Precondition: Here is to seen at a 1kVA toroidal core, how does immediatly after switch on, to the core is going into saturation, because the core will not be changed in his magnetisation from the red curve.

- The red curve shows a dc voltage of 20V, connected to the 230V primary coil of the transformer, via a 100 Ohm resistor, measured after the contact to ground.
- The blue curve shows the induced voltage directly at the primary coil or at the secondary coil.
- The blue curve breaks down after a few milliseconds, (at 15msec.) because of the beginning of saturation from the core, because the starting point was on the positive max. remnance point of the hysteresic loop. (The remnance was setted to + max. before switch on.)



Trafo-Grundlagen-18.bmp, 1kVA Ringkerntr. v. pos Rem. aus mit +20V Sprung, A= Uangel. B= Utreib nach Rv von 100 Ohm.

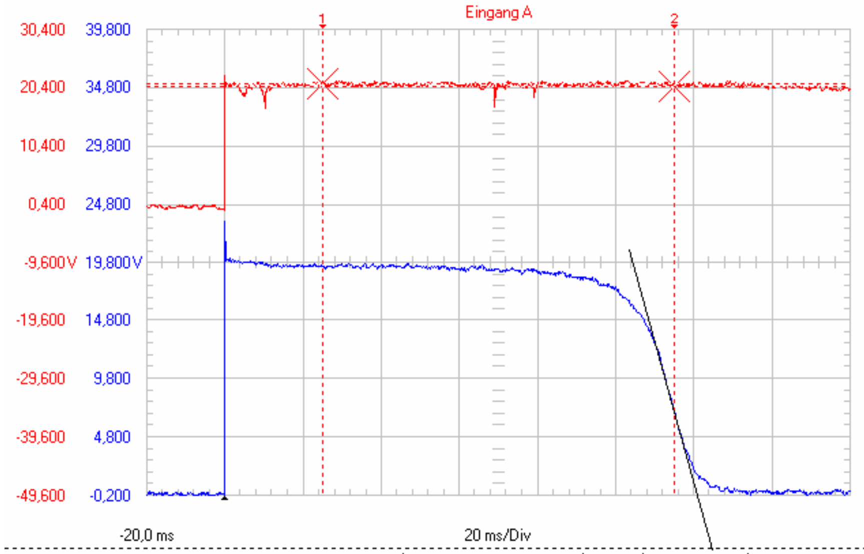
The effective voltage-time-area has only 0,3Vsec., correspond the short way from + remnance to + saturation on the hyst. curve.



See also the shape of the hysteresic loop from the toroidal core.

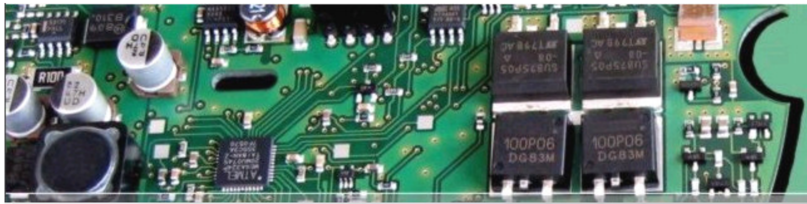
Induction happens only as long as the transformer core is not saturated 2

- The red curve shows the same test voltage like in foil 76 before, see also schematic.
- The blue curve shows the voltage directly at the primary coil, measured like in the foil 76.
- The blue curve falls much later down, than in the foil before, because the core goes later into saturation. (At 120msec.)
- The Remnance was settled before onto the neg. max. Remnance value. That leads to the later saturations time point, because the iron can be changed, in his magnetisation from the pos voltage-time-area of 2 voltseconds.
- The voltage time area changes itself his amaount only over the time, because it´s a dc voltage with a constant hight. The voltage-time-area is changing himself with a constant velocity, leading to a constant hight of the induced voltage, the blue curve until saturation is reached.



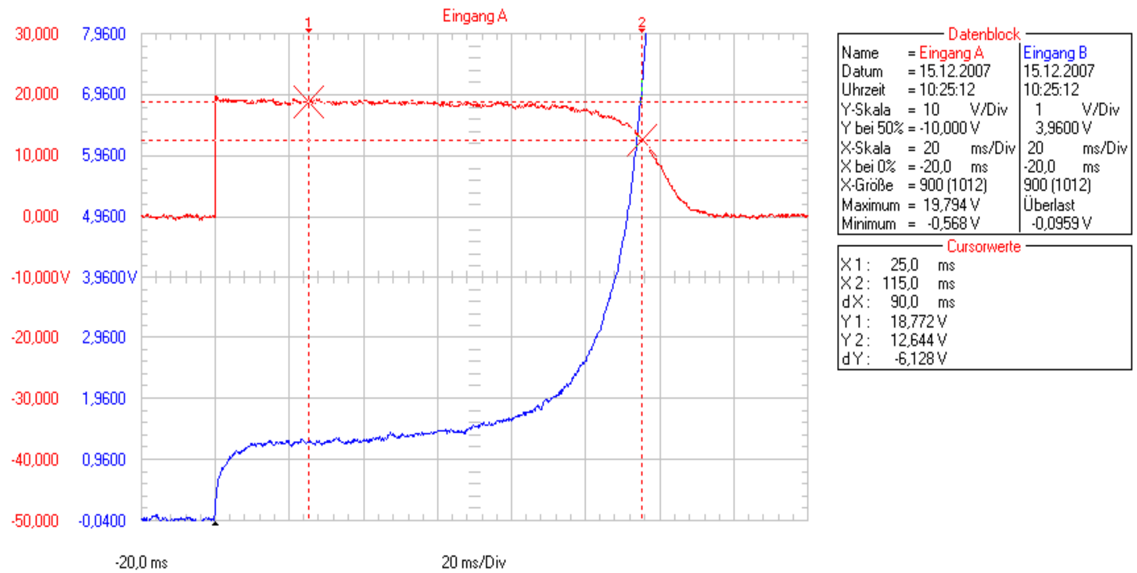
Trafo-grundlagen-19.bmp, Ringkerntr. wie Bild 1, jedoch von neg. Rem. aus +20V Sprung.
Korrektur : wie Bild 18

Same schematic drawing as before: The effective voltage-time-area has an amount of 2 Voltseconds and has the same area like an half wave from the 230V grid at 50Hz, the primary voltage from this transfo.



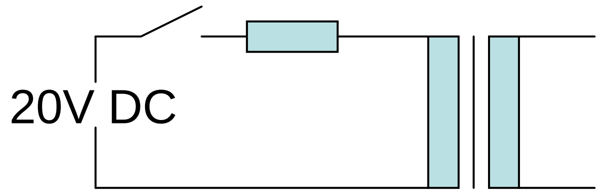
Induction happens only as long as the transformer core is not saturated -3

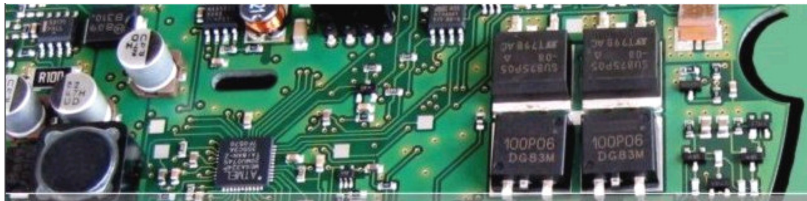
- This measuring shows the effect of an dc voltage, connected to the primary transformer coil via a a 100 Ohm resistor.
- Same schematic as before.
- The voltage, the red curve is now directly measured at the coil, other than in the two foils before.
- If the saturation is reached, the red curve breaks down and
- The blue curve shows the rising current in the case of saturation, flowing into the coil.
- The current stays as long on a low level as no saturation occurs. He rises, if the core is going into saturation. The voltage is then falling to zero.
  The remnance was settled before switch on, to negative max. value.



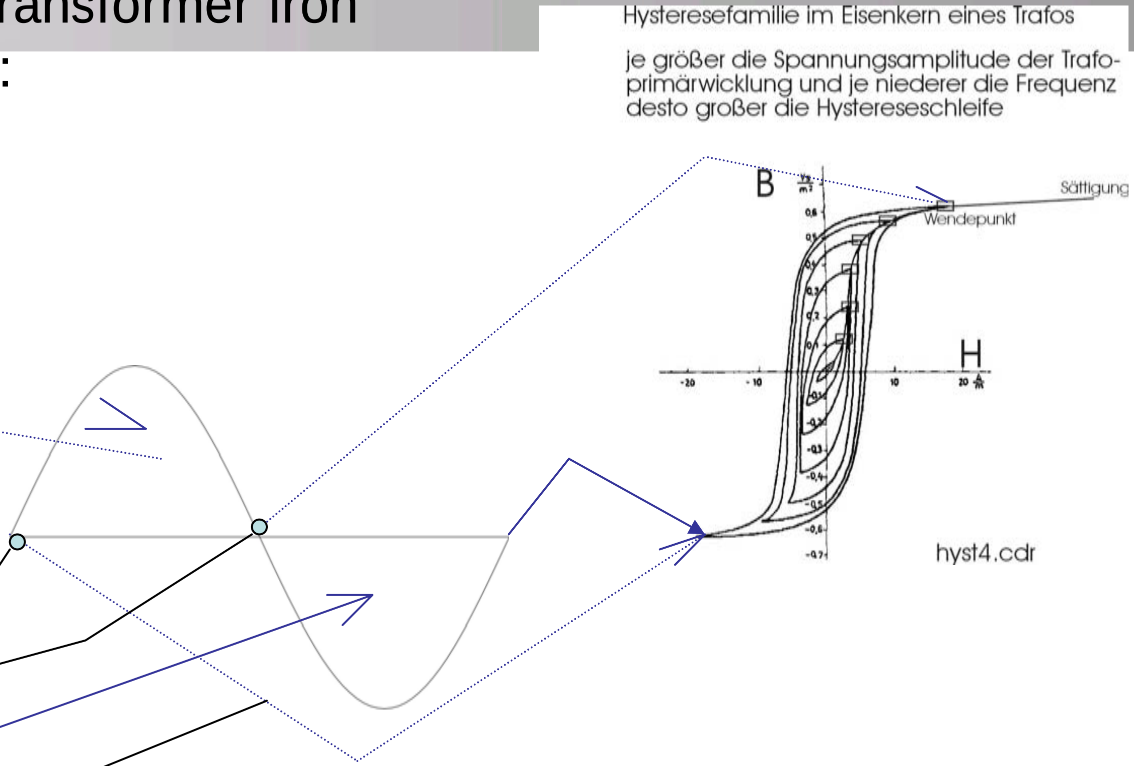
Trafo-grundlagen-17.bmp, Ringkerntrafo 1kva, von neg. Remanenz aus mit p
os.kleinem Sprung. A=Utreib, B= U an Rv mit 100 Ohm, also 10mA/div

Like foils before only with other measuring points.





What happens in the transformer iron core-1, one more time:



While continuous operation:

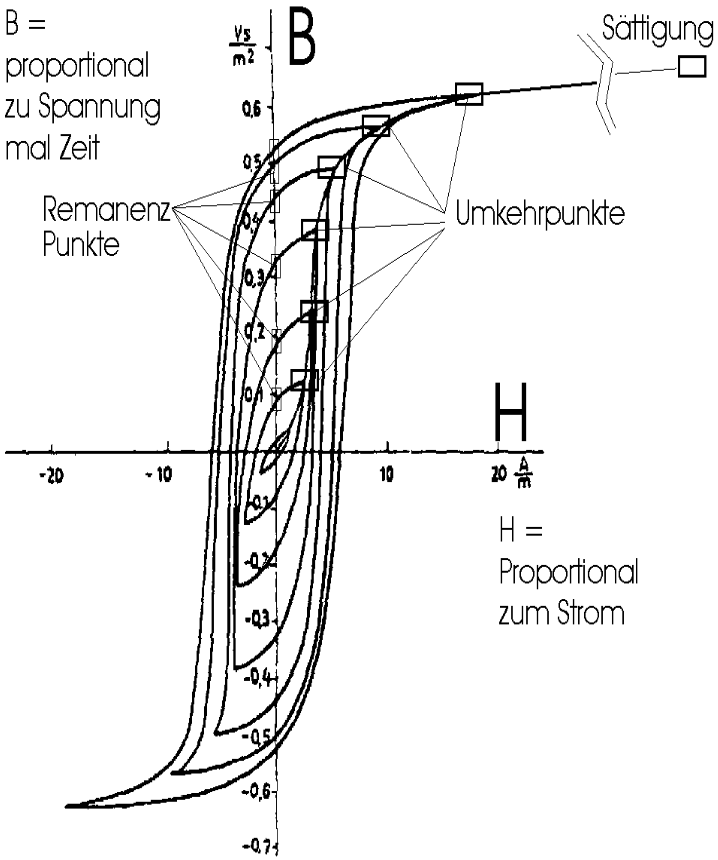
The primary voltage cycles are changing the dense of magnetisation B, in a permanently manner.

- The positive Voltage-halfcycle transports the amplitude of the magnetisation B, from the negative to the positive return point of the hysteresic loop, reaching it at the end of the pos. halfcycle.
- The negative Voltage-halfcycle, brings back the B to the negative returning point of the hysteresic loop.
- And so on and on.

Only the voltage-time-area of an Voltage half wave **is responsible for this transportation of the B**. (The no-load-primary current is only the answer from the transfo.) With the voltage-time-area of a fullwave, see on top, the amplitude of the magnetisation B, walks around the hysteresic loop one time.

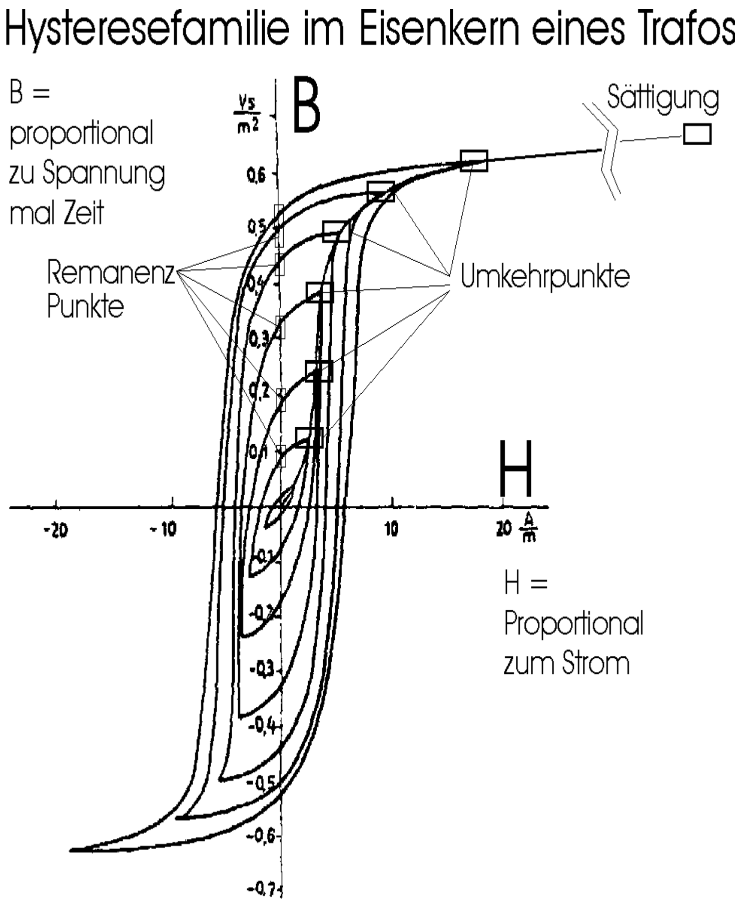
The course of B onto the Hysteresic loop is depending of the Voltage time area-1.

Hysteresefamilie im Eisenkern eines Trafos



- While continuos running, the core is to be permanently changed in his B between his end points of the curve, up and down, plus and minus. (Thats the function princip of the transformer.)
- One voltage half wave transports, the B onto the Hysteresic loop from one end point to the opposite.
- Is the voltage time area smaller or lower, than the b curse runs onto a smaller curve more inside.
- That can happen from a lower voltage or a lower periode time,
- or if the coil gets more windings at the same voltage and frequence.

The course of B onto the Hysteresic loop is depending of the Voltage time area-2.

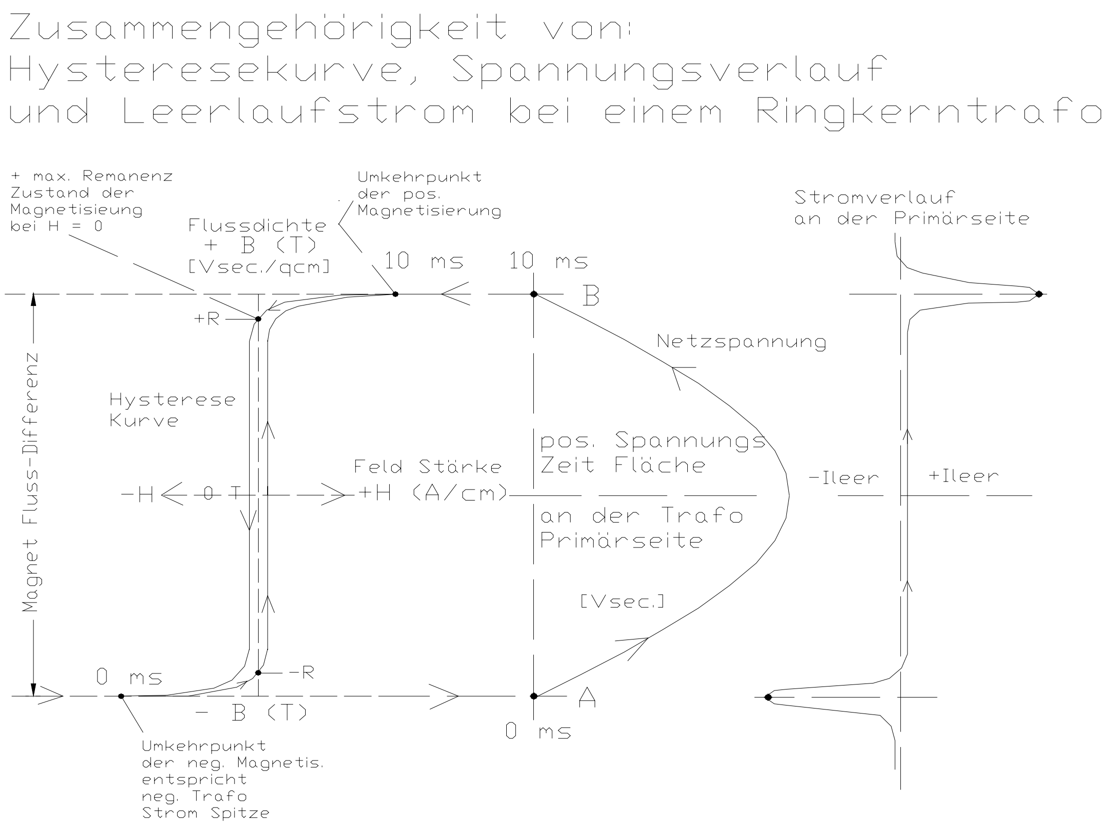


On which layer of the onion shaped curves, the B is running, is depending from the voltage and the time of periode at a given amount of windings.
A smaller time of periode, example at 60Hz, opposite to 50Hz, or a lower hight of voltage amplitude is following to a smaller, more inside laying curve.

Example proof: A transfo made for 60Hz has a max. Inrush current of 12 times the nominal current. He produce if he runs with 50 Hz, at the same voltage, an more higher inrush, example of 15 times, because the B is running now onto a broader curve and reaches earlier the saturation at the end of a voltage half wave, than at 60 Hz.

Course from B over H, Voltage and current over the belonged timepart.

- This drawing ist not to find in an teaching book. But this can be measured of each person itself who want that to know, with an 2 channel oscilloscope for voltage and current.
- She shows like the B is to be transported trough the voltage time area from each half wave, and like the current peaks comes into being.
- The measured noload current is proportional to the field strenght in the iron core and has its peak at the end of the hysteresic loop, because of a small saturation of the core.
- Thats also a proof for the influence of the voltage time areas.



Hysteresic loop B over H | Voltage half wave U over t | Current I over t

The TSR is using small and unipolarly, voltage time areas

- To influence the magnetisation softly.
- In respect to the physically laws and the shape of the different Hysteresicloops, at differnt iron core shapes of the transformers, is it that what the TSR Softstart procedure has at the content.

  The flow dense B is be brought first with the premagnetising to a point onto the hysteresic loop knowed to the TSR and after that the transformer is to be switched (full) on.

Hysteresic loops measuring itself.

In the Literatur you can find many proposals to measure the Hysteresic loops with Lissajous Figurs with an Oscilloscop.-

Here is one proposal.

WWW.fh-uesseldorf.de/DOCS/FB/MUV/staniek/dokumente/hysterese.htm

I hope now all is clear??

- Really understand you this only if you work practically with an transformer, an TSR, an 2 channel oscilloscope to measure voltage and current at different shapes of transformers. If you deadjust the TSR, Trafoschaltrelais, you can see and understand what happens inside a transformer, much better like with calculations of formulas.

Thanks for your attention.

More to know about the TSR and the transformer physic you can get here:

www.EMEKO.de