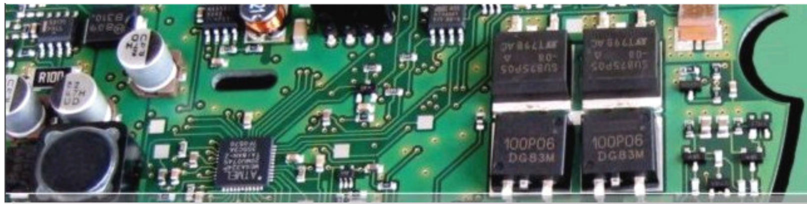


Avoiding of Transformer Inrush currents with a Transformer–Switching-Relay TSR, and an Explanation of the physical basics of transformers. Speech to explain the Softstart procedure of the TSR.

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.

The explanation of the detailled physical rules inside the transformer follows in the second part of this speech away from foil 54:

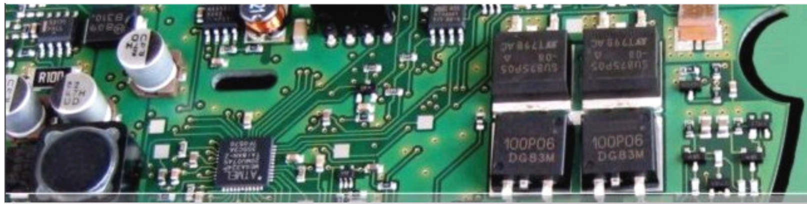
Transformers always are producing inrush current peaks!

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

230V Primär — Ohne Einschaltstrombegrenzung

Trafo-Typ	Leistung	strom Pr.	Inrush	automaten B-Char.	C-Char.	K-Char.	Schmelz-Sicherung 5 * 20 m		PKZM- Bereich	PKZM-T Bereich	PKZM-T 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.

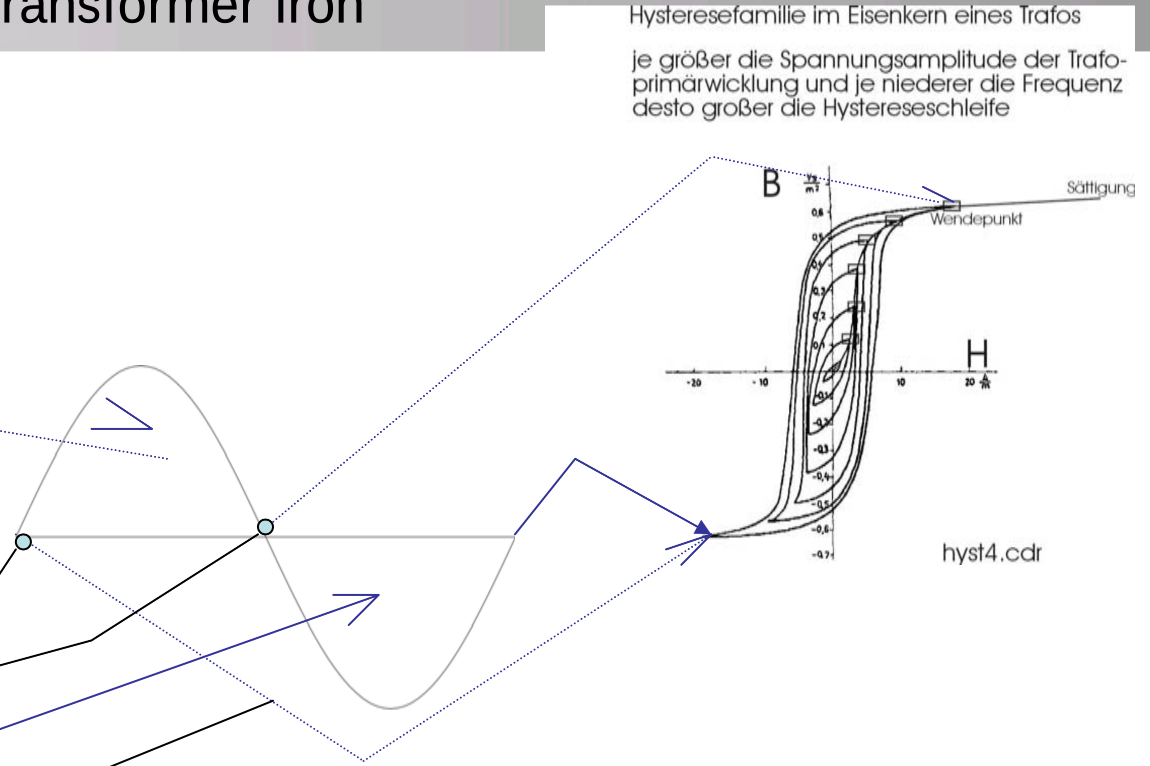
Without avoiding of the insrush current that leads to foolish fuse values. An 1600VA or bigger toroidal Transformer size is not fusible with elements listed in top.

What happens in the transformer iron core-1:

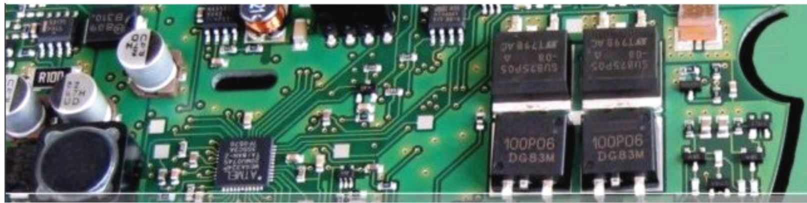
While continuous operation:

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.



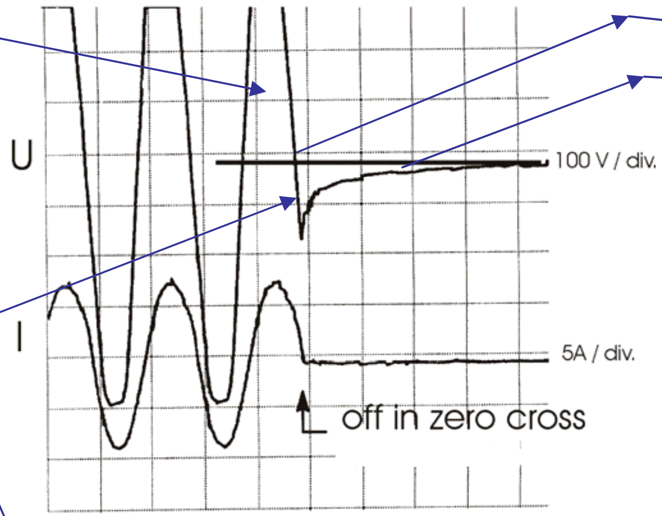
What happens in the transformer iron core-2 :

- **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

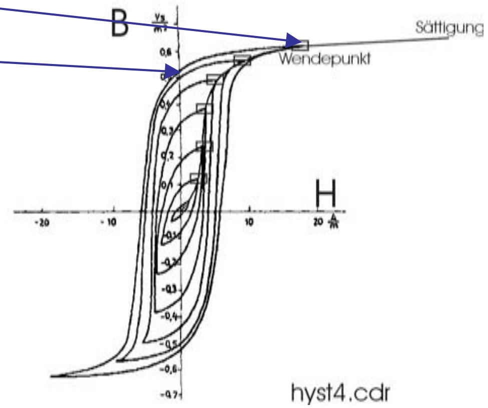
loaded 1kVA transformer switch off with TSE.

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



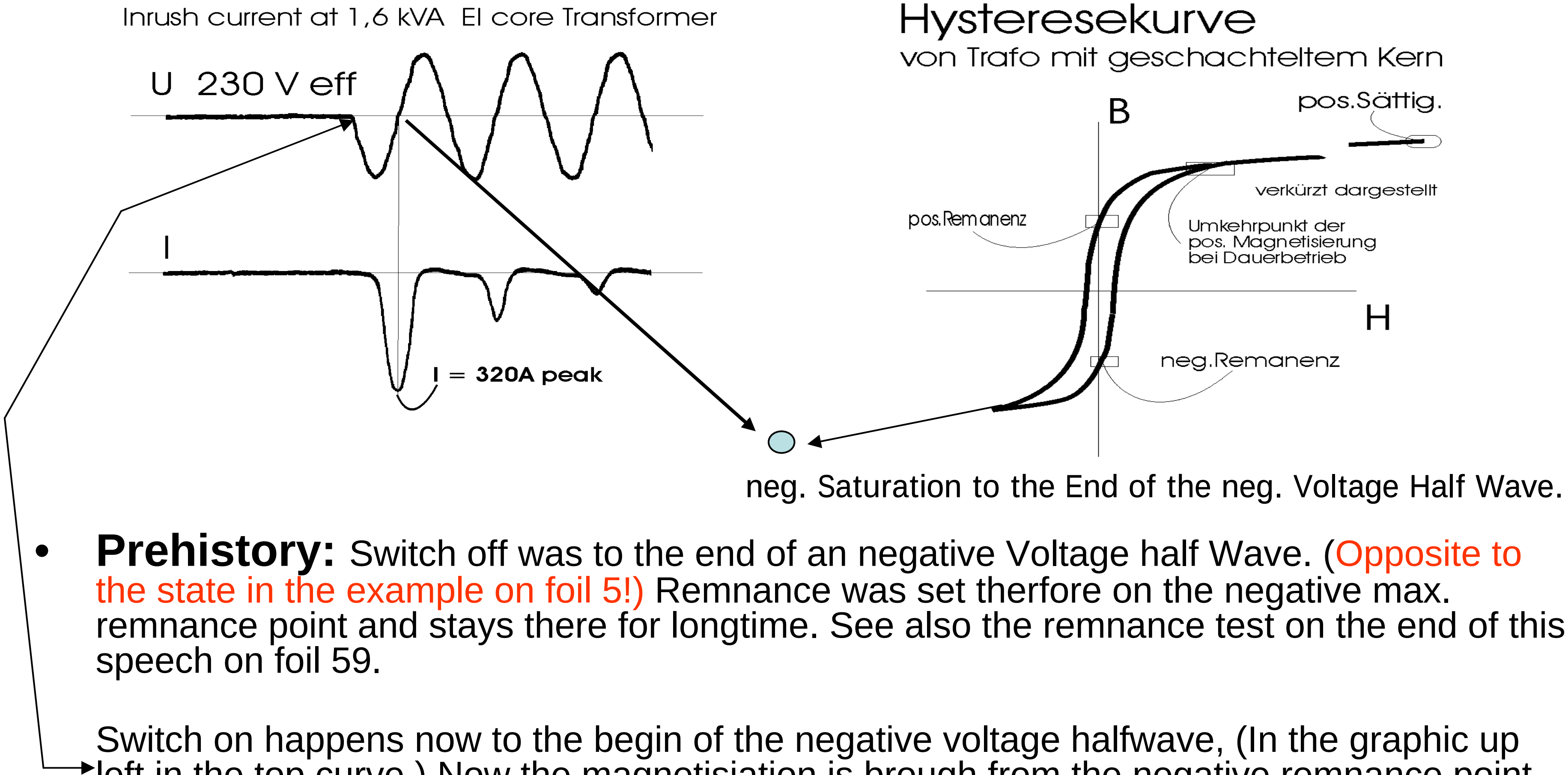
Hysteresefamilie im Eisenkern eines Trafos

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:



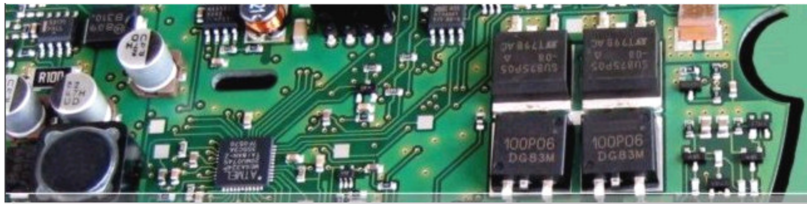
neg. Saturation to the End of the neg. Voltage Half Wave.

- **Prehistory:** Switch off was to the end of an negative Voltage half Wave. (Opposite to the state in the example on foil 5!) Remnance was set therfore on the negative max. remnance point and stays there for longtime. See also the remnance test on the end of this speech on foil 59.

  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. See on foil 59. 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.

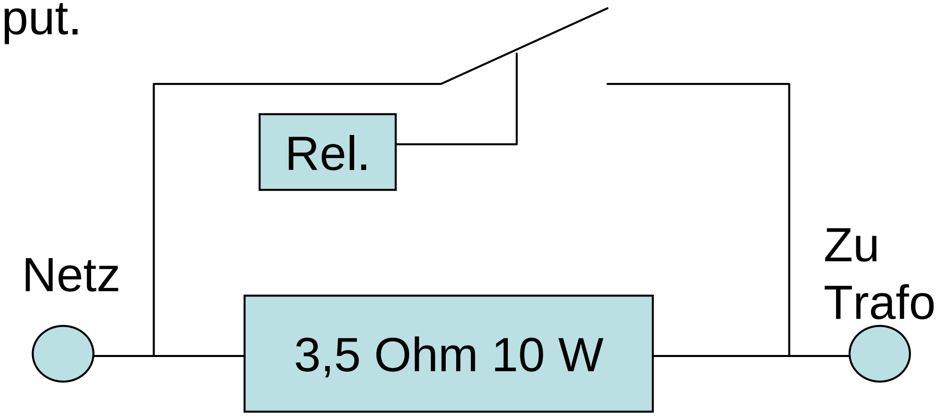
- For that circumstance the current rises to very high amplitudes!
- In the case of iron core saturation, only the primary coil copper resistance added to the Grid line impedance is limiting the current for this half wave of the voltage. In this case the inductive resistance of the transformer is lost.
- 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.

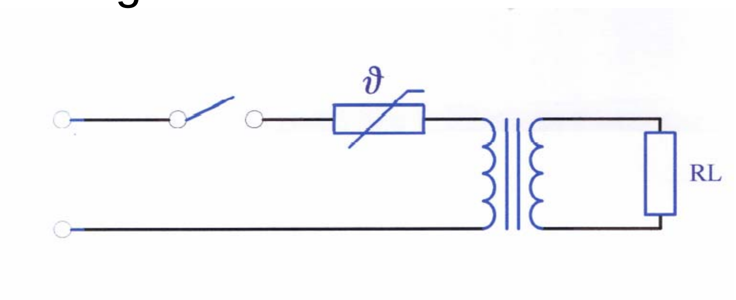
Standard methodes to limit the inrush current, the „Ein-Schaltstrom-Begrenzer“, ESB.

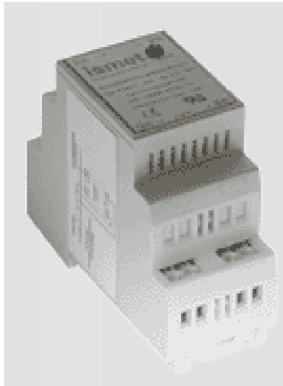
Start with an additionally resistor in the input.

➔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:

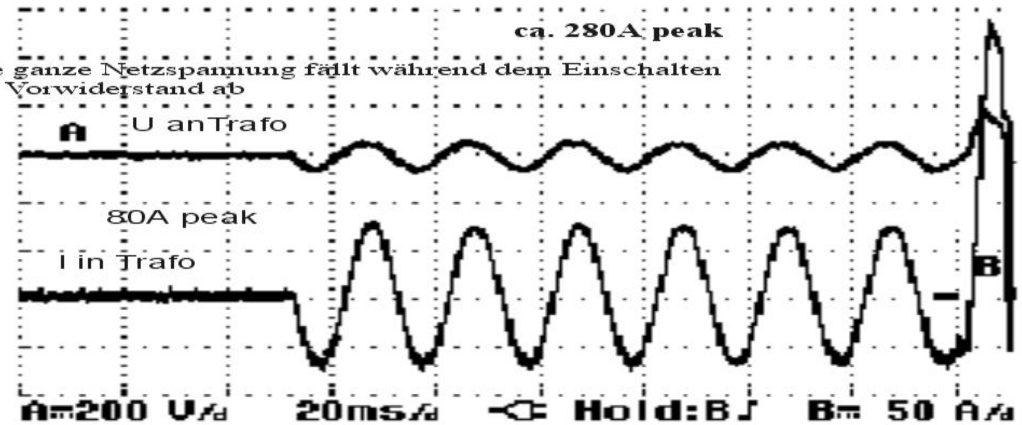
U_{PRI}: 110 - 400 V

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

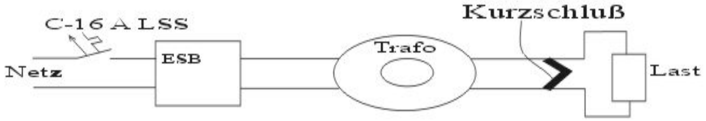
Transformatoren schalten. Mit ESB

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..

Die ganze Netzspannung fällt während dem Einschalten am Vorwiderstand ab



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.

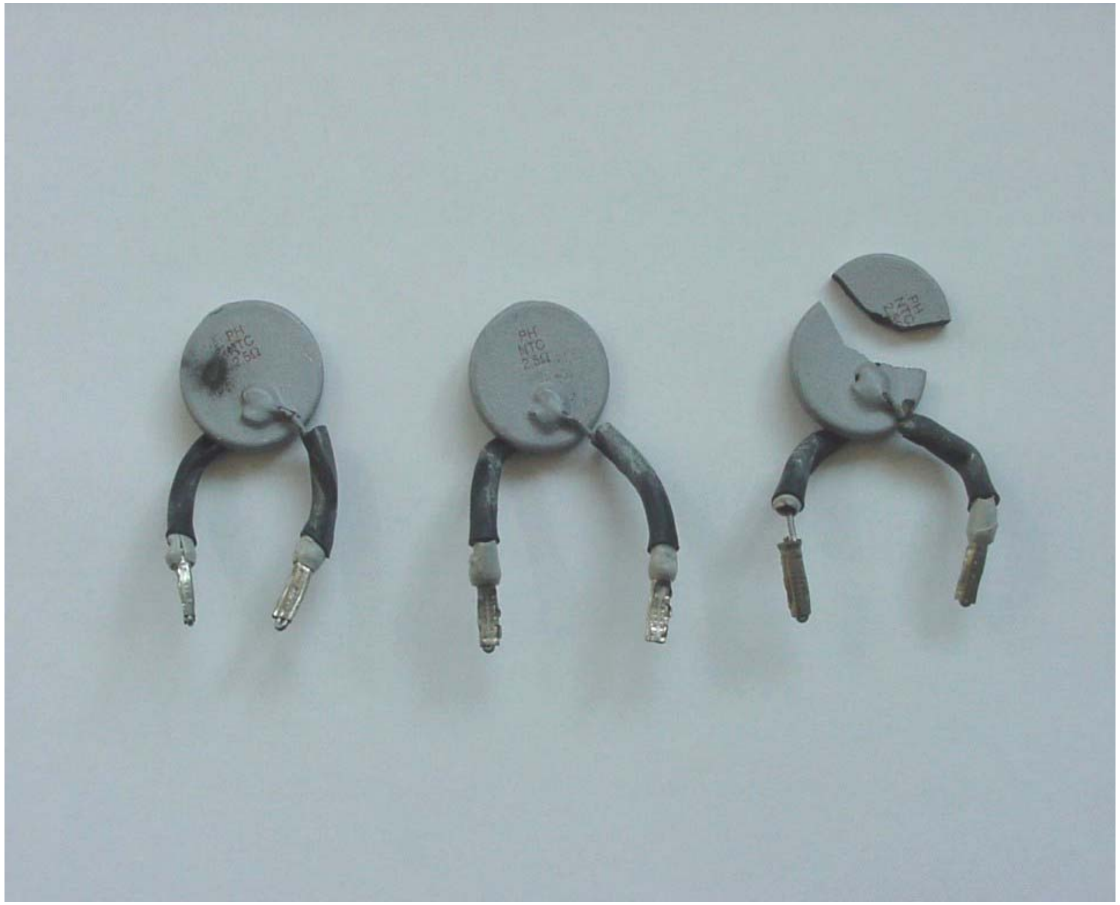


EMEKO, esbkzschl.cdr,

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. The effect of the voltage dips on to a transformer is declaired later in this speech, away from foil 33. And therefore much of our customers are producers of electro medical equipments.

Resume of the disadvantages of ESB´s.

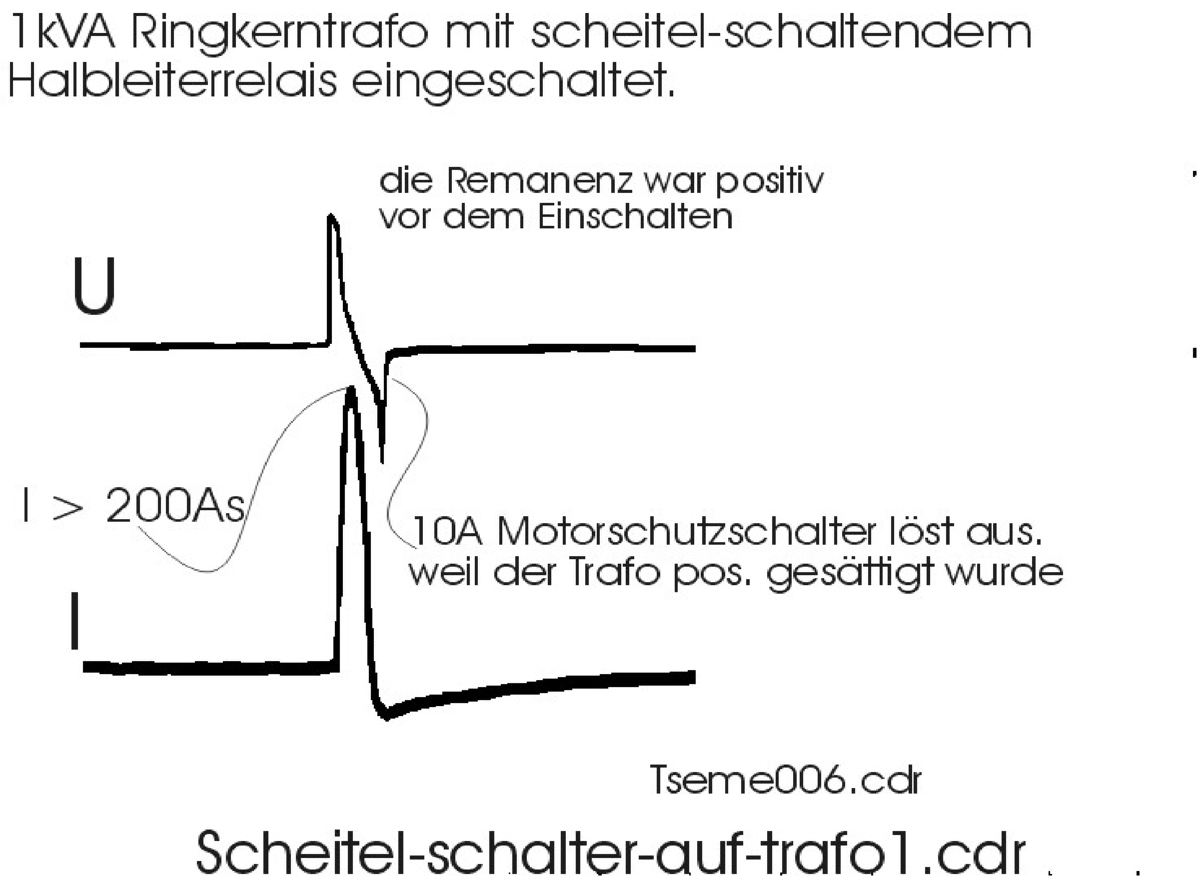
There are also other limits for ESB´s. Those are:

- 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.

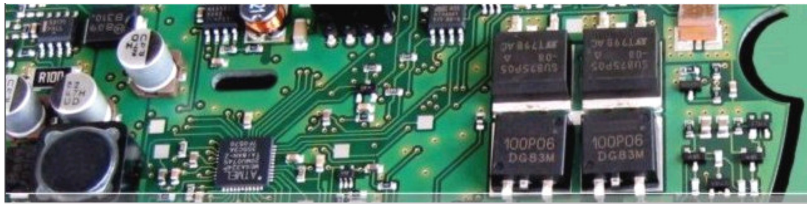
- Although any producers of solid state relays are telling, tor start an transformer the switch on with an peakvoltage switcher ist the best whot you can do.
- But the result is to seen in the graphic at right, if switch on to an toroidal transfo.
- Also in the scientific literature ist often be written, 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.



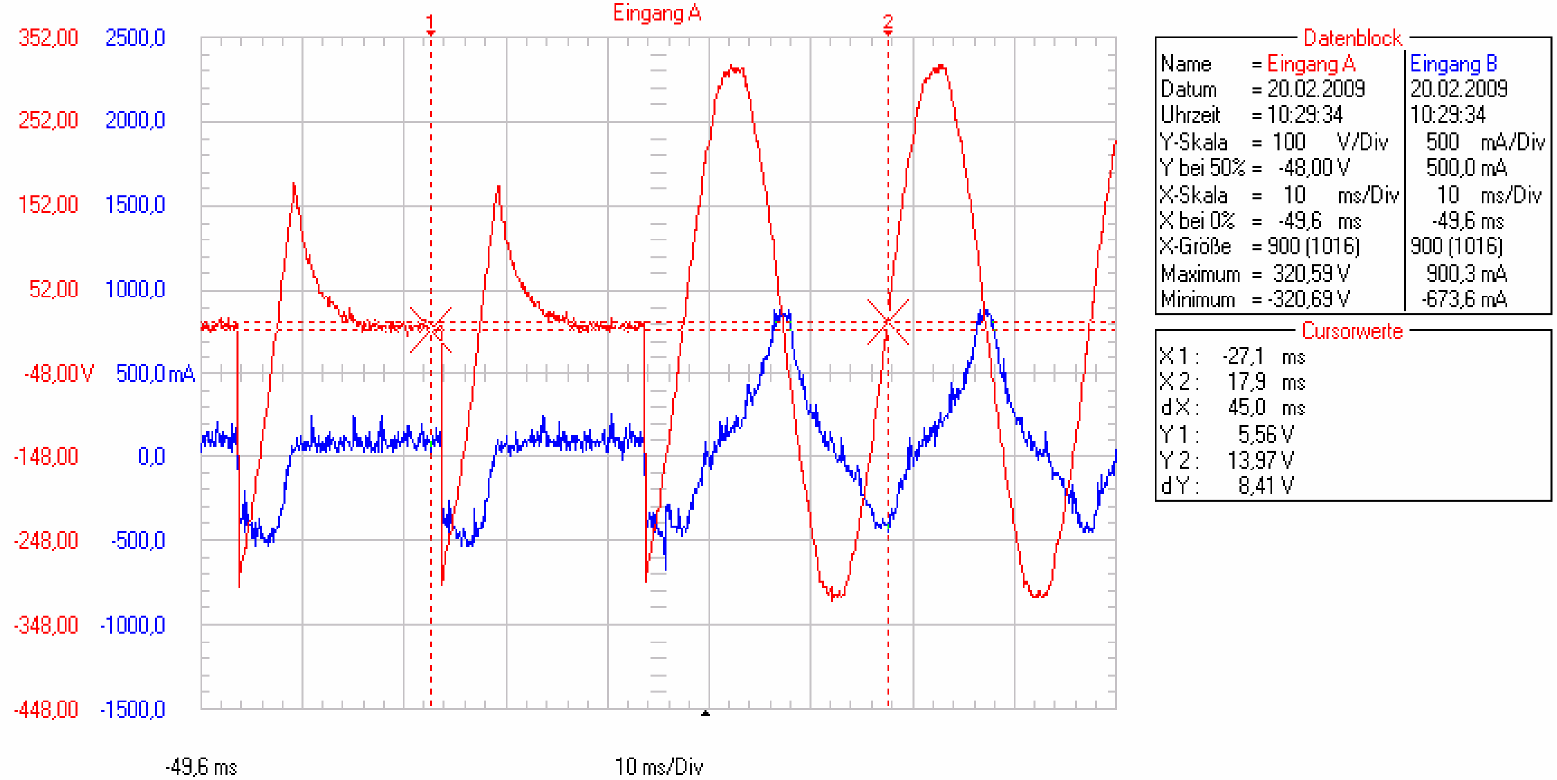
A TSR is not an inrush current limiter, he avoids the inrush.

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 away from foil 55..
- Following is showed, how the TSR does it´s switching, and where the TSR is used and which advantages then you can have with it.

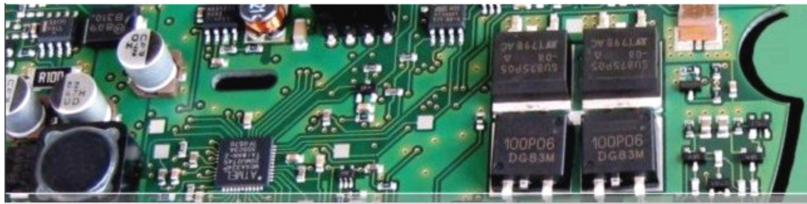


TSRL Starting procedure with only the flowing of the off-load current at an 1kVA EI-weldedcore transfo if he is in off-load state.

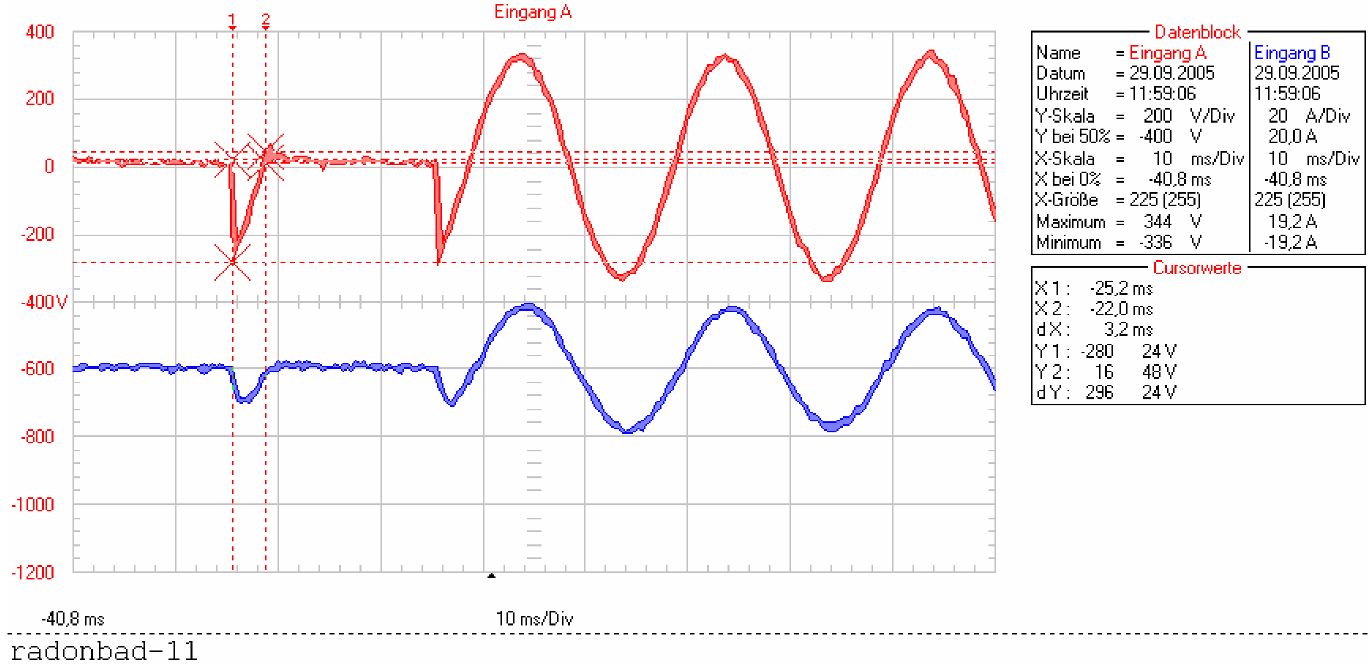


TSRL-EI-1kVA-einschaltenimleerl-14.bmp

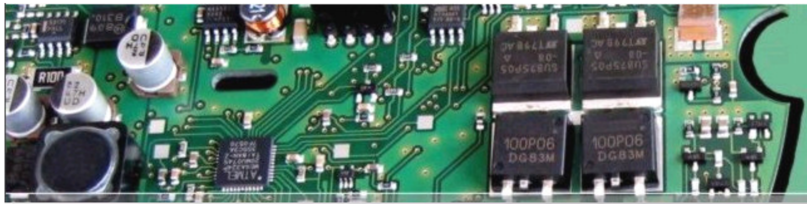
- Red curve: Voltage at transfo. Blue curve: Current into transfo. Scalefactor is 0,5 A / div.. (Directly after full on switching, just the off-load current is flowing, knowing on his typically shape.)
- Can anybody make a better transformer start??



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

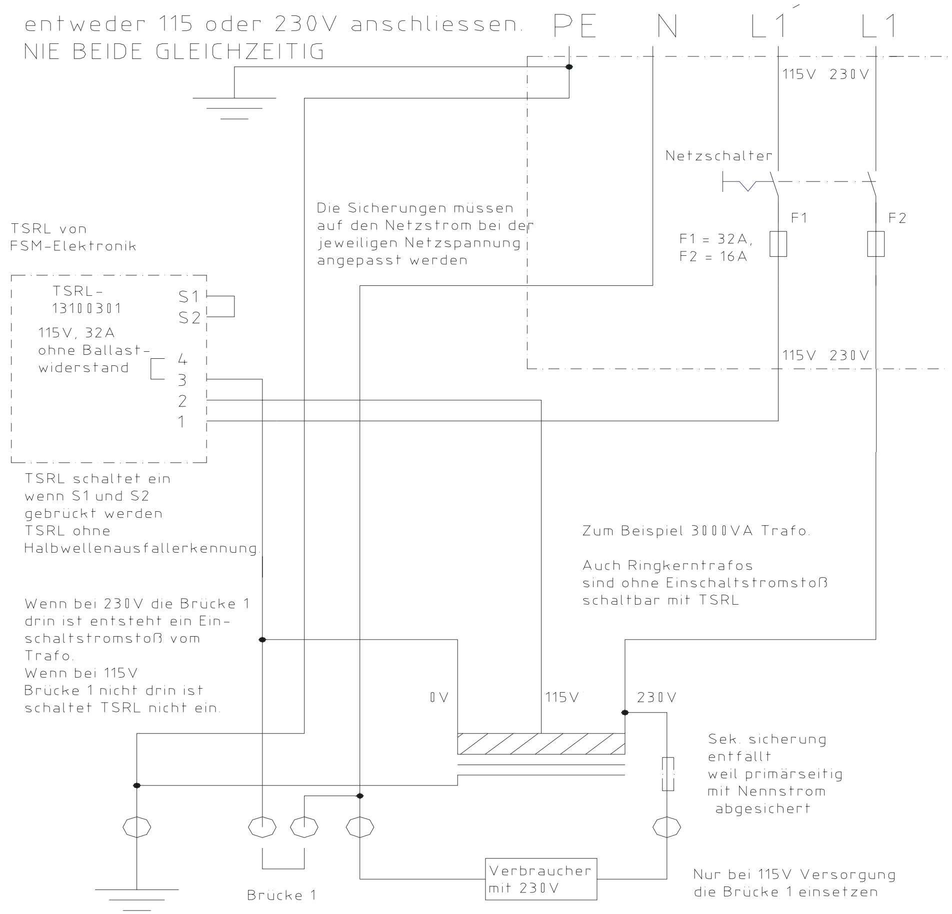


- Red curve, voltage on the transformer clamps. Blue curve: current into transformer. Scale factor is 20A per div.
- No inductive current peaks are seen only the resistive current from the load.
- No difference in Switch on behaviour between noload and load at the same adjusting of the high and width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

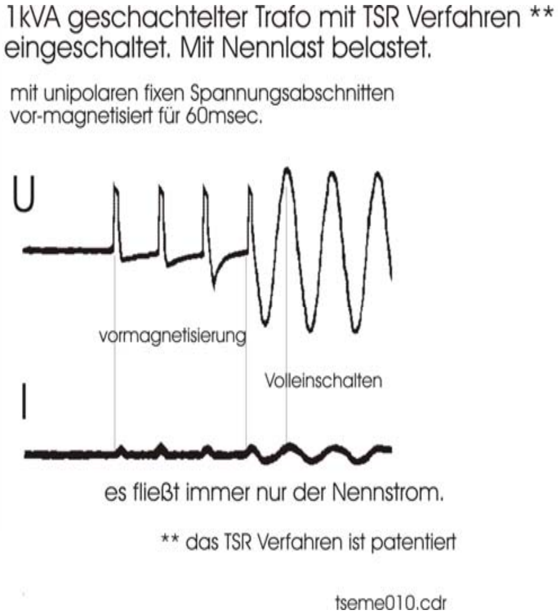


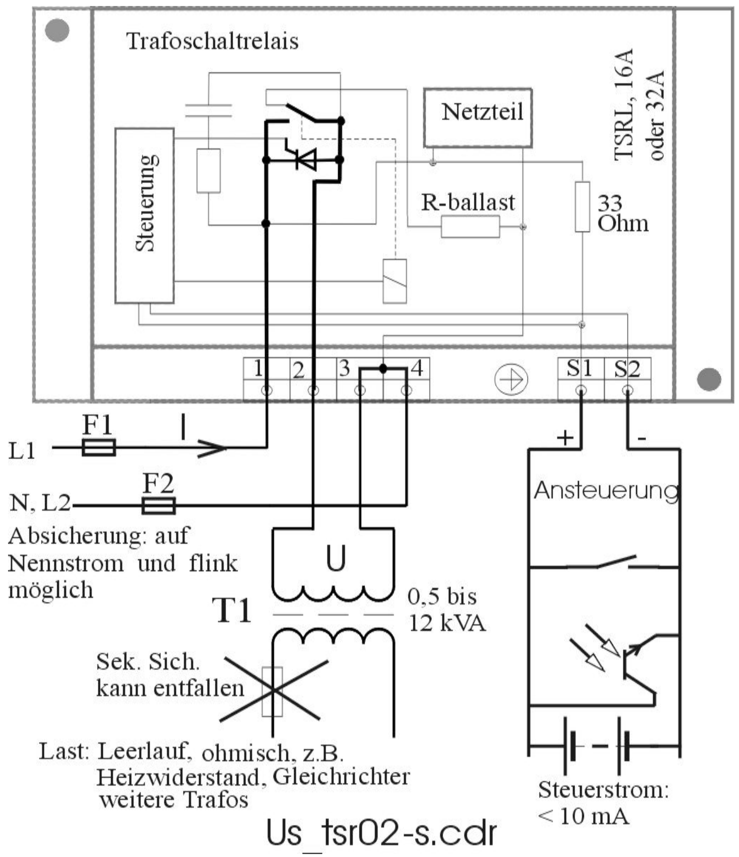
One from „about 1000“ different Applications of the TSRL.

- 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.

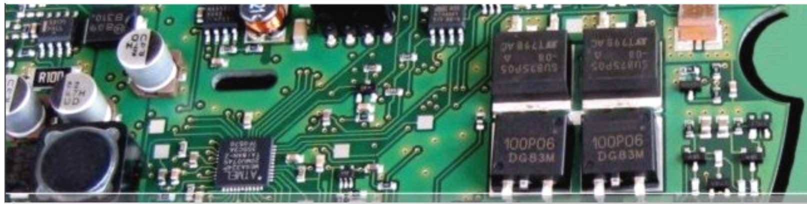


The Transformer-Switching-Relay, Function und drawing scheme.





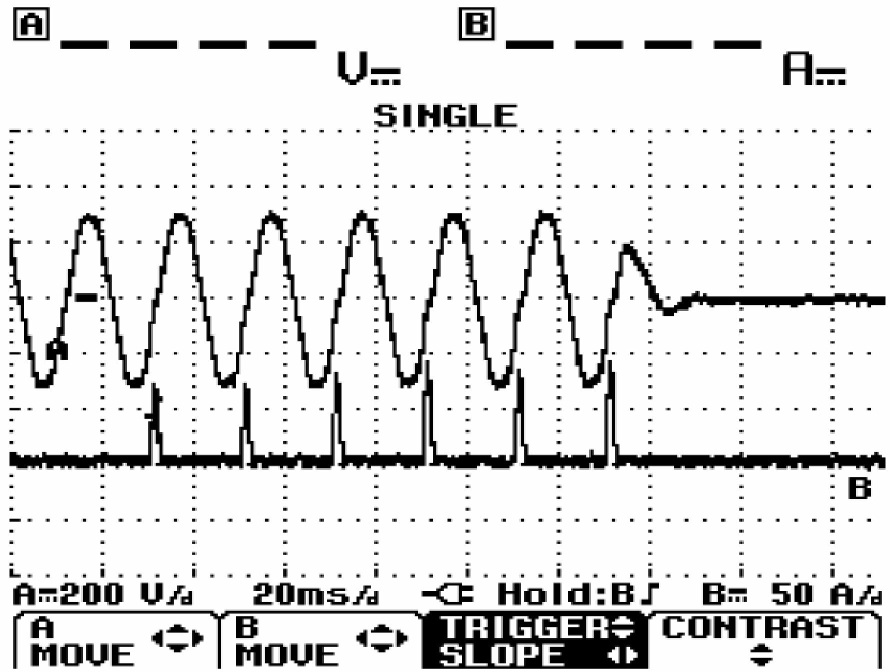
The TSRL, as an bridged solid state relay, correspond EN60947-4-3, is switching in a soft manner, without a Pre-Resistor, and therefore load **un**-depending. The premagnetissing cycle transports with small unipolar voltage time areas the Magnetisation B, to the right point to switch on in a physically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



EMEKO and FSM

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.

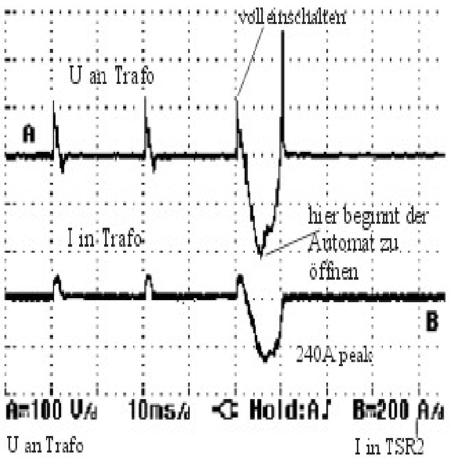


2kVA Rktr.mit sek Kurzschluß einge-
schaltet. I in Trafo 80A peak, (Ausl
ösg. bei 60A peak.) mit R10A B-Typ
Leitungssch.sch. abgesichert,
schon beim vormagn.ausgelöst. A= U
nach Sicherung.
17.11.98 Emeko
Ing.Büro D79114 Freiburg
tsf103.fvf

The TSRL is short ciurcuit proof under normally* circumstances -2.

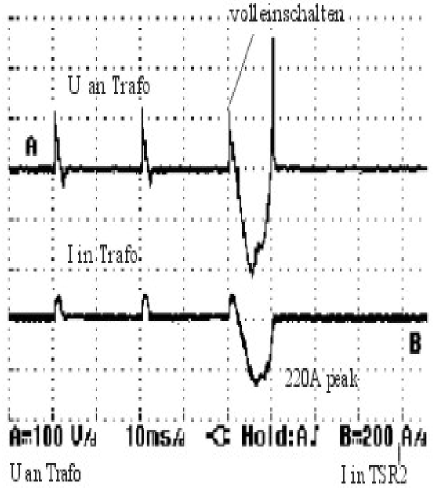
Einschalten von kurzgeschlossenem Rigkerntrafo mit dem TSR

2 kVA Ringkerntrafo mit sekundären Kurzschluß mit TSR2 eingeschaltet.
Mit 16A B-Typ Leitungsschutzschalter abgesichert, der erst bei volleinschalten auslöst.
(Ein R-10A Automat hätte schon beim Vormagnetisieren ausgelöst.)
Der TSR und natürlich der Leitungsschutzschalter bleiben dabei unbeschädigt.
Der vorgeschaltete C 16A Automat hat dabei auch ausgelöst.



Mit B 16A LSS fused

2 kVA Ringkerntrafo mit sekundären Kurzschluß mit TSR2 eingeschaltet.
Mit 10A B-Typ Leitungsschutzschalter abgesichert, der erst bei volleinschalten auslöst.
(Ein R-10A Automat hätte schon beim Vormagnetisieren ausgelöst.)
Der TSR und natürlich der Leitungsschutzschalter bleiben dabei unbeschädigt.
Der vorgeschaltete C 16A Automat hat dabei auch ausgelöst.



Mit B 10A LSS fused

- While premagnetising the B- 10A LSS line protector switch does not trip.
- When switching full on the mechanical relay bridges the Thyristor.
- TheThyristor can lead 500 A for 10 msec., but he must lead here only 80A for 2msec., also no problem for him.
- The mechanical Relais can lead 500A for 10msec., but he must lead here only 240A for 10msec..
- **Notice:**
  An B 10A Lineprotectorswitch is not selective to an C 16A Lineprotectorswitch.
- But a B10 Lineprotectorswitch is selectiv to a preconncted 25A- gL fuse, if the max. current is < 1kA.
- (That means if Ik < 1kA only the B10A Lineprotectorswitch is tripping and not the 25AgL fuse.)
- That shows significant, that an 25AgL fuse is enough for a 6kVA bis 10 KVA medically IT-Transfo in future together with an TSR and not an 50A fuse must built in.

Has a TSR the risc to get defective, if he starts an Medically IT-separation transformer, if he gets a short circuit? Can be reached a fuse selectivity from the secondary B10A Line breaker to the 25AgL primary fuses?

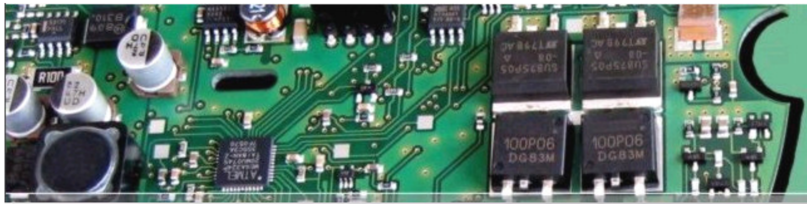
- If a 25A gL or a 50A gL melting fuse is fusing the cable going to the separation transformer in a medically environment via an TSRL, and if occurs an short circuit in the medically area after the separation transformer in a connector box, the TSRL has not get a risc to get damaged, because the cable from the separation transformers output is fused with an B10A Lineprotectorswitch.
- Example: The cables after the transformer are laid short protection proof, and are fused after the cable with a Lineprotectorswitch of B10A. The single phase transformer has 400V to 230V and a size of 10kVA. The short circuit current is not higher than 500A peak for one half cycle into the cables after the transformer, because of their current limiting characteristic from powercord cables and connectorplugs. Wat you can see on the foils before, shows that the TSRL has no risc, because the current into him is not higher than 230/400 * 500A = 290Apeak .
- The 20AgL o the 25AgL or the 50AgL fuse not trips, because the B 10A Lineprotectorswitch is tripping inside the first half cycle of the short circuit current peak. No higher current than 300Apeak is flowing into the TSRL. The B10A Lineprotectorswitch starts to open after 5 msec. and limits for that also the max. current in the peak point. See also the following table sheet from Schupa on the foil 23.
- The selectivity is guarantee. Only the B10 A Lineprotectorswitch is tripping.

Selectivity overview for an example of an 230/230V * Transfo.

Distributed from „Schupa“, a producer of Lineprotectorswitches .
Current-Selectivity in case of short circuit to preconnected melting gL/gg fuses.
values in **kA** until the nominal switching capacity of the Lineprotectorswitch, LPS, if he can handle up to 6kA max..

Values for gL/gl melting fuses with:	20A	25A	35A	50A
The max. short circuit current is allowed then to.				
For B10A LPS :	**0,4kA**	**1kA**	**1,5kA**	**3kA**
For B16A LPS :	**----**	**0,6kA**	**1,5kA**	**2,5kA**

Until the **showed short circuit amplitudes** consist a selectivity in the short circuit case to the preconnected melting fuse in front of the transformer.
In the most of all grid circuits, no higher values than 0,4kA after the grid connectorplugs are reached in case of a short circuit.
* In case of an 400V to 230V Transformer the selectivity is higher for this values, because of the current reduction of the primary side.



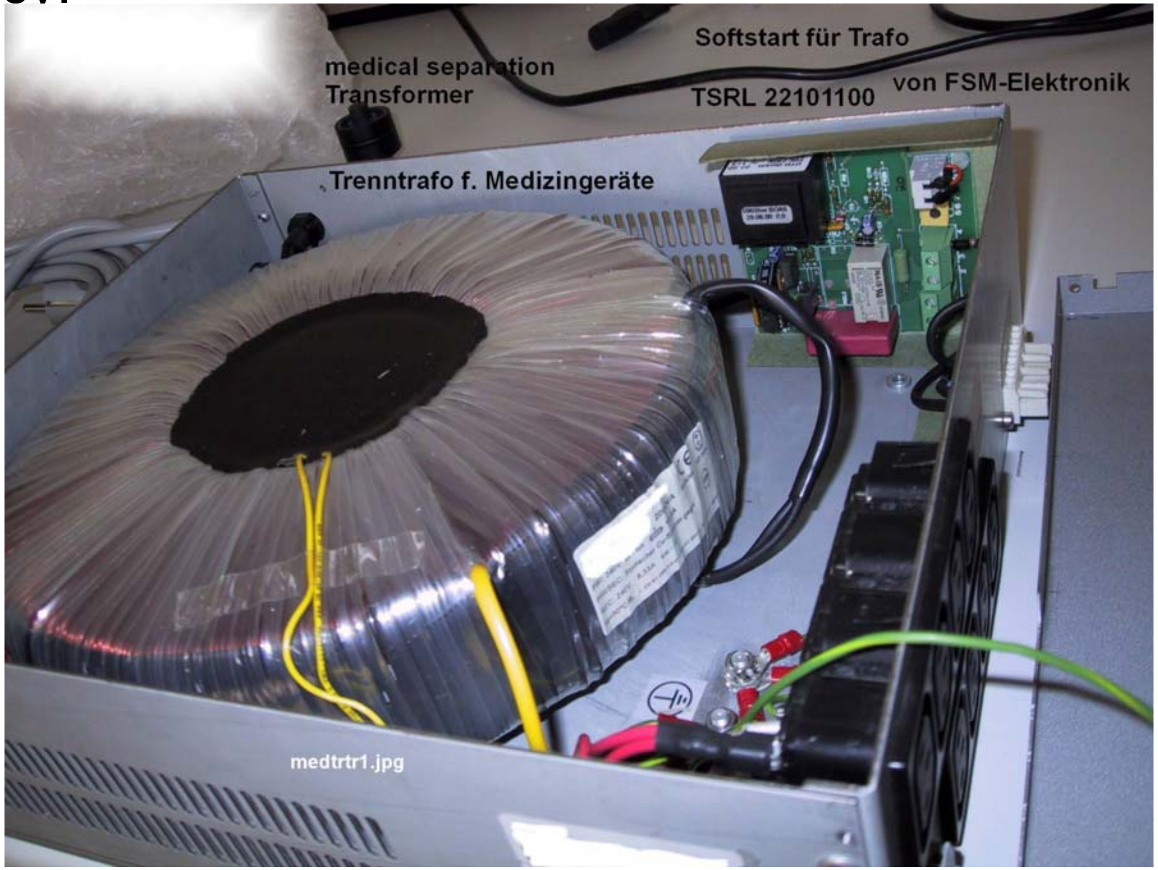
Overview of the advantages if you take an TSR.

- No more inrush current peaks. Start only with off-load currents if the transformer is unloaded. (Line switch is saved.)
- With a loaded transformer, only the load current is flowing if switch on a transformer.
- Fusing with nominal current values and fast tripping possible. (Also a fusing with lower values than nominal current is possible, if transfo is not full loaded.)
- No waiting time need between the single starting procedures.
- No inrush current peak after voltage dips, proof again tripping fuses when tested correspond EN 61000-4-11 and medical equipment EN 60601.
- TSR short circuit proof.
- More than 5 Millions switch on cycles lifetime under nominal load conditions.
- No fail from the bridging relay contact, if he is closed for a long time without acting.
- The frequently apply of the TSR in secure sensitive areas shows, how robust he is, like sowed in the following examples.

The TSRL board is placed in the box for an medically separation transformer, here for an endoscopy trolley.

Such a Separation Transformer is placed in the bottom of many medically trolley carts. He correspond the EN60601 and the EN61000-4-11 tests for all Elektro-Medically equipments.

In many such transformer boxes a TSRL is built in for avoiding the high valued inrush current peaks in all circumstances. More than 100.000 times since 2002.

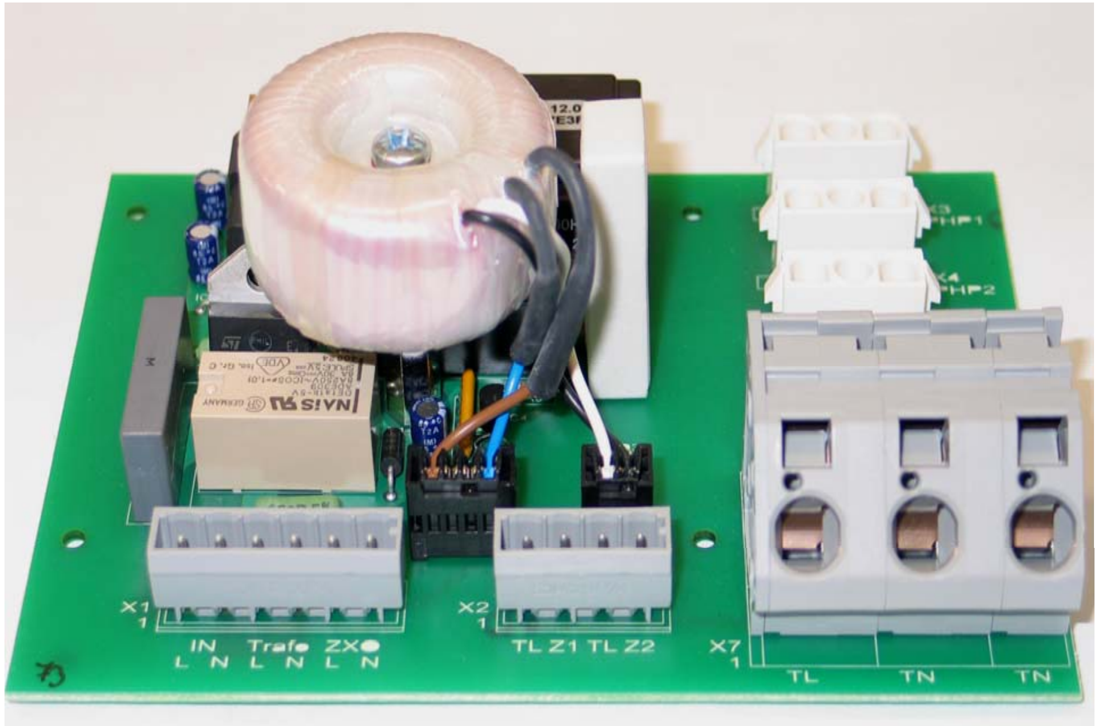


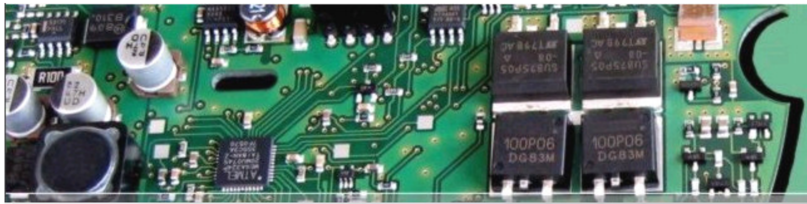
And consider: The grid is fused with an B10A line circuit breaker.

A customer specific TSR- board for traffic light signals.

- A customer specific TSRL for traffic lights with the new LED-Technique.
  The TSRL switches the 2kVA 230V to 40V AC toroidal core Transformer who feed the trafic lights.
- And he must switch off for a short time each day to test the security chain and switch on after a very short pause off less than 50msec..
- More than 50.000 Installatios since 2004.

  This shows the confidence to the TSR from our customers for the reliability of it.





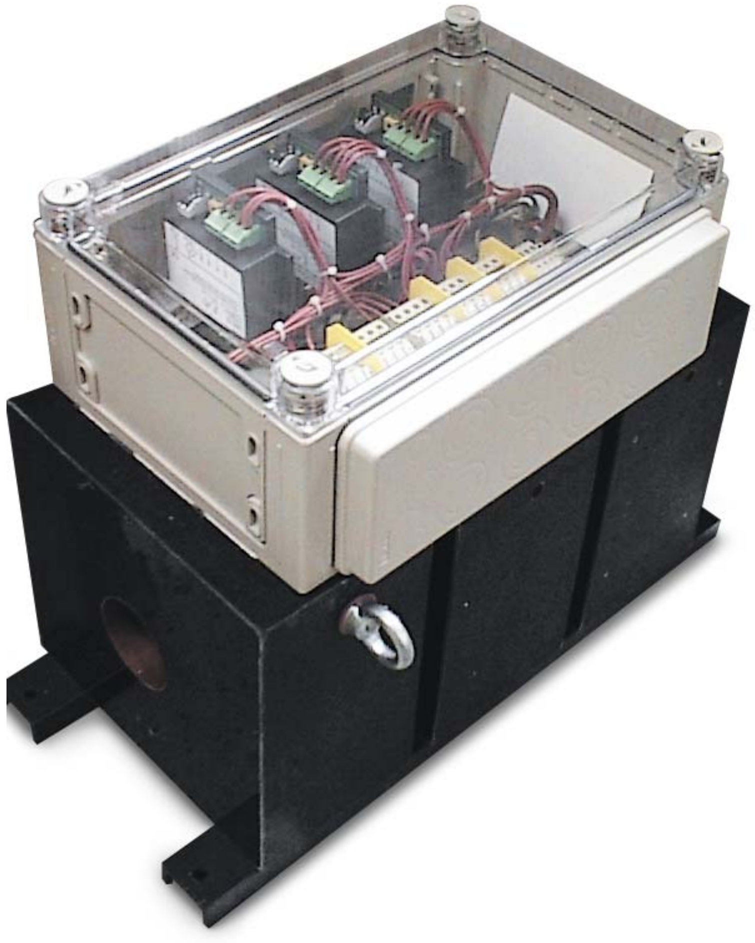
Security is very important.

- At television transmitting cars is the grid feeding in from extern duty via a separation-transformer inside the car. Respond of her light weight, toroidal transformers are mostly used for that.
- For first aid cars, THW, Firebrigade cars, and so on, should not be used the so called inrush current limiter working with pre resistors, says the ministery of internals..
- They suggest to take the TSRL to avoid the inrush currents in those cars.

- Also together with separation Transformers für Hospitals for the I-T- grids shall no inrush current limiters be used, built with preresistors. (EN 61558)

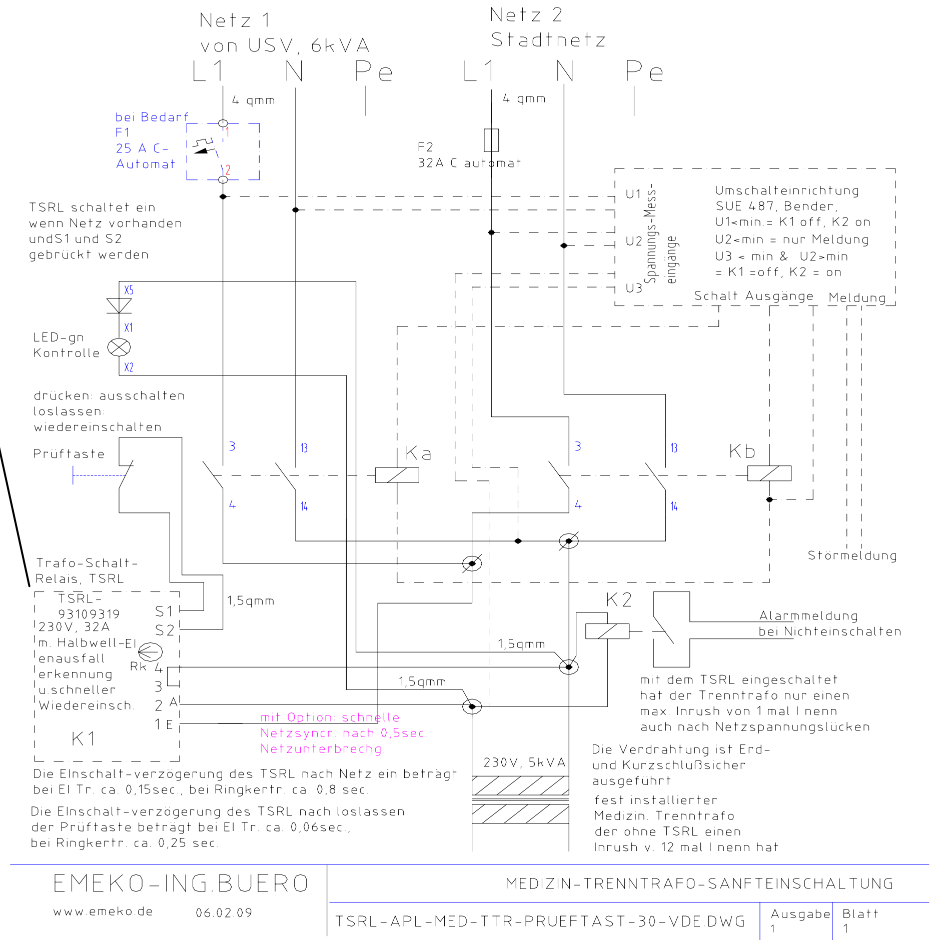
Apply of TSRL inside of medically Separationtransformers.

- Since 2004 Fa. Ruhstrat applys the TSRL for IT-transformers. Up to the End of 2010 more than 400 times.
- They are using toroidal Transformers, -3 black blocks in the picture-, and are avoiding the inrush current peaks with the TSRL, mounted in box on top..



Supplement for a security check out of the TSRL with an additional test knob and an failure Signaling relays, in medically applications.

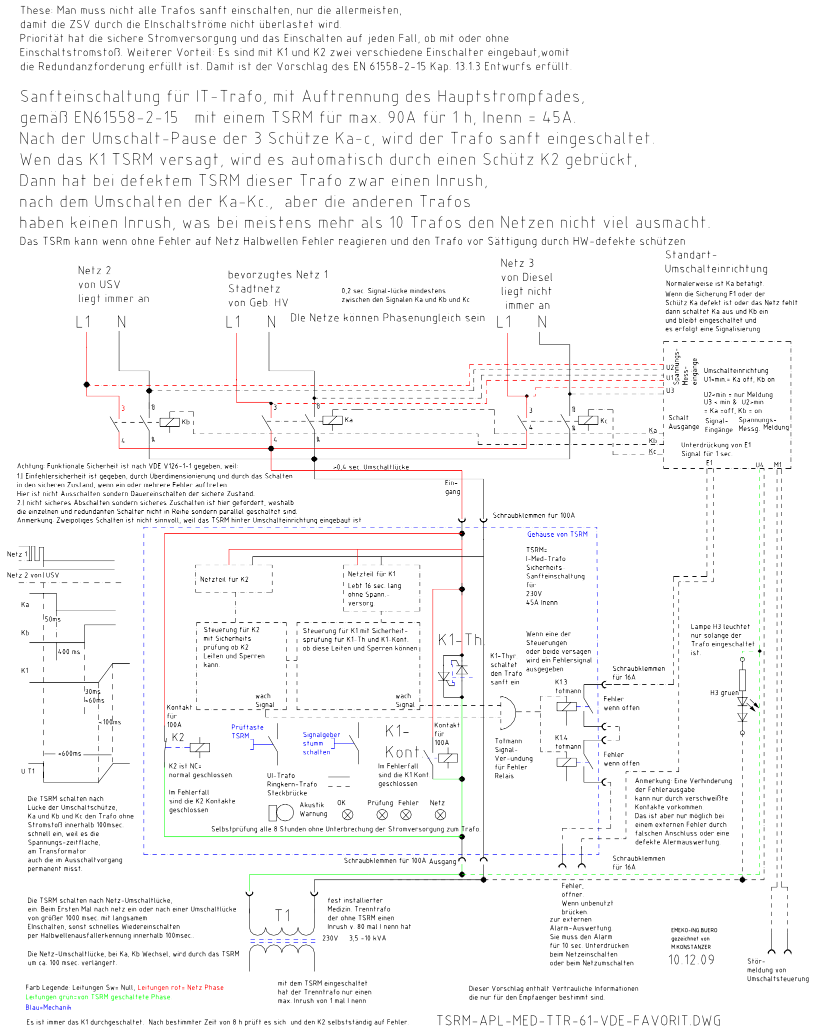
- To test periodically for working correct of the TSRL.
- When pressing the test knob opener, (Prueftaste), the TSRL K1 switches off, the green LED goes dark and the alarm Relays K2 opens his contacts to allow to test the alrm signaling path for correct working.
- After release of the knob, the TSRL restart the transformer without inrush current peak.
- This shall only be done if no danger for the patients life inside the room exists.



EMEKO and FSM

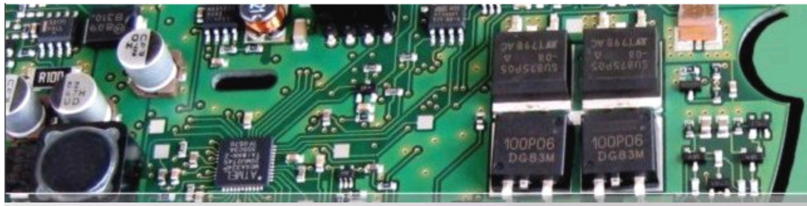
A Future project: A TSRM with a self check and a failure signaling relays.

- TSRM (TSR for Medically Transfos), with an in built self test, and failure signaling.
- security against the first failure, because of 2 redundancy current path inside the TSRM.
- If pressing the test knob, (Prüftaste TSRM), occurs an alternativly switch off of one of the two current path. Correspond Signal light goes dark and the alarm Relay gives a signal. But the transfo stays on the grid via the other current path.
- That allows a test without influence of the function of the transformer.
- If pressing the test knob for a longer time, both current path inside TSRM are switching off.
- After release of the test knob, follows a restart with a soft start without an inrush current peak.
- This ideas are to be discussed in the EN 61558 Gremium.



A TSR can solve also other problems!

- With the sight out from the Grid and fuse in the direction to the transformer, the inrush current is a bad disturbance for grid an fuse.
- (Therefore Voltage sags occures and fuses can trip.)
- With the sight out from the transformer in direction to the grid, are Voltage-Dips a disturbance which can provocate other following inrush current peaks trough the transformer saturation. See later more to this thema.
- With the sight out from the transformer in direction to the load, is the short current or the overload a big disturbance. (High Mechanical forces are pulling on the wires inside the coils, Overtemperatur of the transformer can occur).
- With the sight out from the load in the direction to the grid, a to fast or a to slow rising of the voltage after a switch on is a disturbance. (Produces Capacitive inrush current peaks together with rectifier loads and caps, or a bad restart of control elements if contactors are getting an ac voltage rising to slow.)
- **A TSRL with his soft start also for capacitors can solve all this problems** because he fills the capacitors slowly and he has discrete thresholds for switch on and off, with an hysteresis for the grid voltage.
  He Starts when grid rises 180V, he stops if grid falls under 150V, at the 230V unit.



EMEKO and FSM

In deed the Inrush current is some times higher then allowed -1.

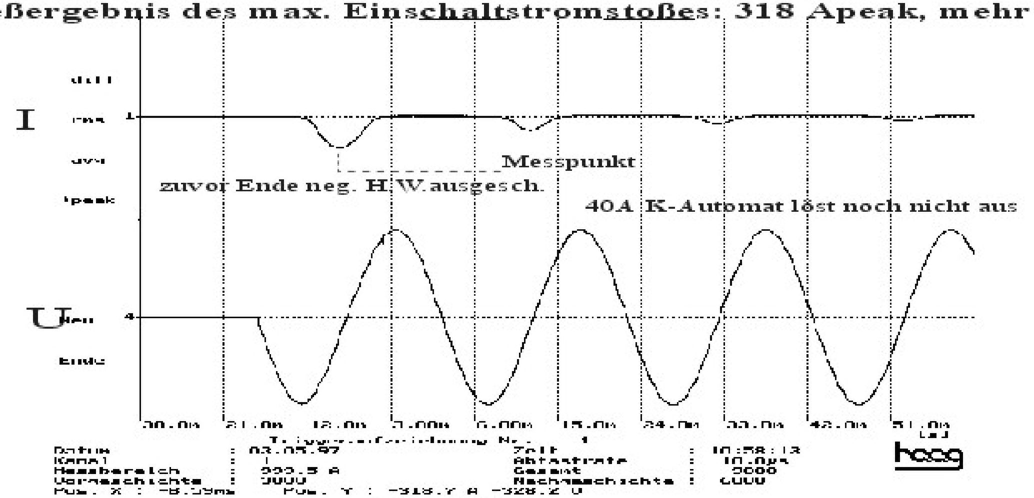
Example for an
1 Sec. during loss of grid voltage.

Showed is the reaction of an medically IT-grid Transfo with an allowed Inrush current of 8 times Inominal.

But here are measured an inrush of 17 times **I-nominal.** Leading to problems for the „Diesel engine“ when any such transformers are starting at the same time.

Einschaltstromstoß-Test verschiedener Trafos im Leerlauf.
Prüfgerät: IRST0, Inrush-Stimulator, Zuleitung mit 10m mit 16qmm an Hauptvert. und insges. 2m mit 6qmm zu IRST und Prüfling.
Einschaltverfahren: Ende neg. HW. aus- nach 1 Sec. Beg.neg. HW. ein.
Trafotyp:3,15 kVA Medizin Geräte-Trafo m. 1,0 Tesla

Leerlaufstrom: 0,5A Netzspannung: 234V
ges. Netzimpedanz: ca. 0,2 Ohm incl. Absicherung von:
36A NH 00, und Irst0 mit K40 LS Automat:
Modalitäten: an 230V Wicklung des Prüflings angeklemmt.
Meßergebnis des max. Einschaltstromstoßes: 318 Apeak, mehr als berechnet.



Prüfaufbau:

Datum:02.05.1997
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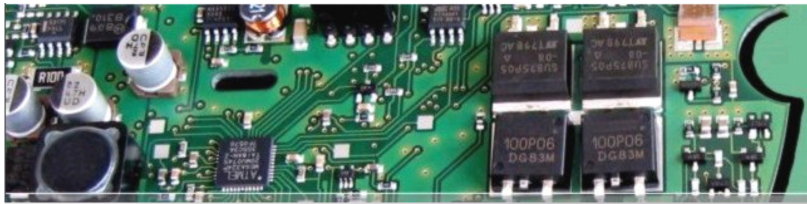


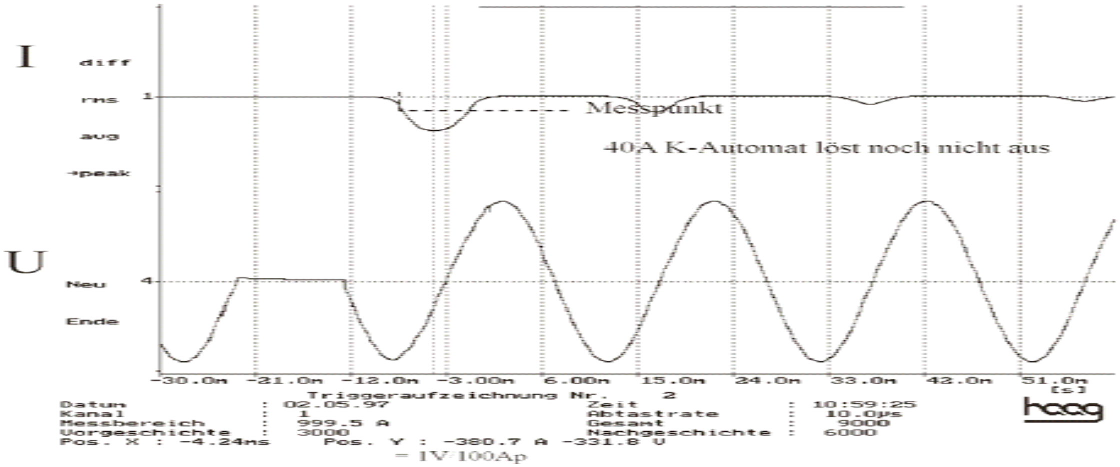
In deed the Inrush current is some times higher then allowed -2.

Example with a voltage dip for 10 msec.correspond EN 61000-4-11.

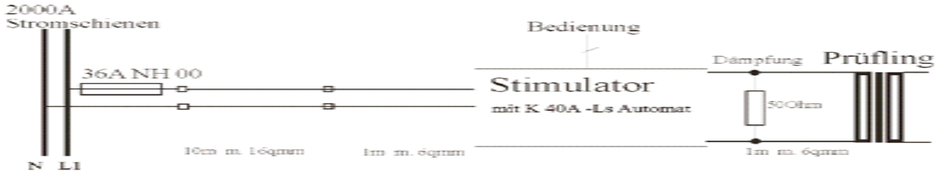
Showed is the reaction of an medically IT-grid Transfo with an allowed Inrush current of 8 times Inominal. But here are measured an inrush of 27 times **I-nominal.** Leading to problems for the „Diesel engine“ when any such transformers are starting at the same time.

Einschaltstromstoß-Test von Medizingeräte Trafo im Leerlauf.
Prüfgerät: Inrush-Stimulator, Zuleitung mit 10m mit 16qmm an Hauptvert. und insges. 2m mit 6qmm zu IRST und Prüfling.
Einschaltverfahren: Halbwellenausfall, provoziert größten Stromstoß
Trafotyp:3,15 kVA Medizin Geräte-Trafo, mit 1,0 Tesla Induktion
und Einschaltstromstoß von kleiner 8 mal Nennstrom = < 154A peak
Netzspannung: 234V
ges. Netzimpedanz: ca. 0,2 Ohm incl. Absicherung von:
36A NH 00, und Stimulator mit K40 LS Automat:
Modalitäten: an 230V Wicklung des Prüflings angeklemmt.

Meßergebnis des max. Einschaltstromstoßes: 380 Apeak,
= 2,45 mal dem zulässigen Einschaltstrom v. 8 mal Inenn.
Fazit: Ohne Softstart ist dieser Fall nicht beherrschbar.



Prüfaufbau:



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Once again someting about the voltage time areas!

- Also in the following foils the „sight with voltage-time-areas“ is very important to easy understand what happens in the transformer core in all of his states.

Effect of an voltage drop for the time of 5 msec..

Netzunterbrechungs-Test verschiedener Trafos im Leerlauf, nach IEC 1000-4-11.

Prüfgerät: IRST0, Inrush-Stimulator, Zuleitung mit 10m mit 16qmm an Hauptvert. und insges. 2m mit 6qmm zu IRST und Prüfling.

Einschaltverfahren: Ende pos. H.W. ausgesch. u. sofort mit 0,5 der 1 neg. Halbwelle eingesch.

Trafotyp: 1,5kVA Ringkerntrafo 230V zu 24V

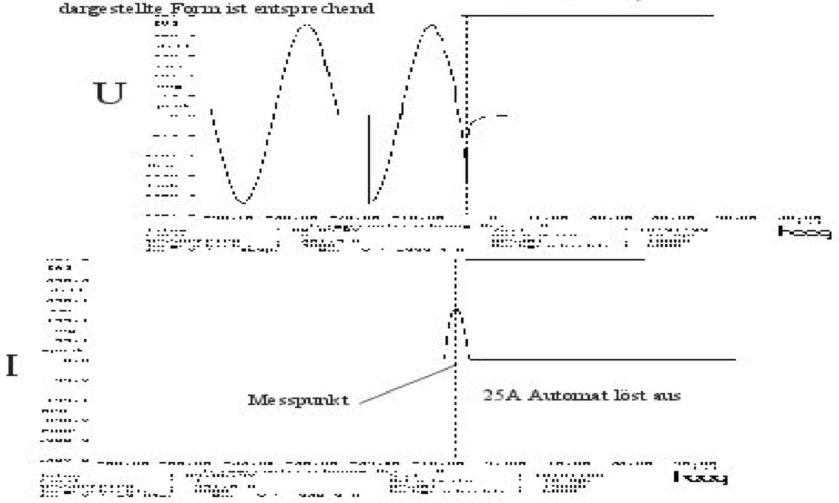
Leerlaufstrom: 0,5Aeff Netzspannung: 234V

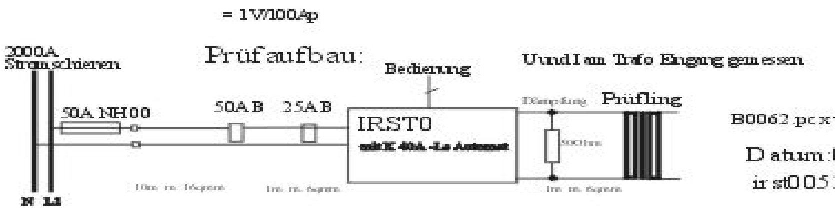
ges. Netzimpedanz: ca. 0,3 Ohm incl. Absicherung von: 50A NH 00, + 50A +25A, B-typ Ls-schalter:

Modalitäten: an 230V Wicklung des Prüflings angeklemmt.

Meßergebnis des max. Einschaltstromstoßes: 250 Apeak

TEST nach EMV Norm IEC 1000-4-11 100% Einbruch für 0,5 Halbwelle dargestellte Form ist entsprechend





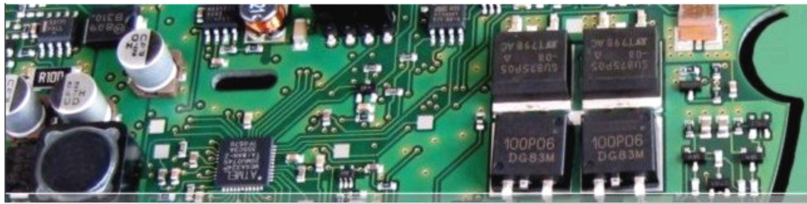
B0062.pcx u. B0063.pcx

Datum: 09.05.1997

irst0052.cdr

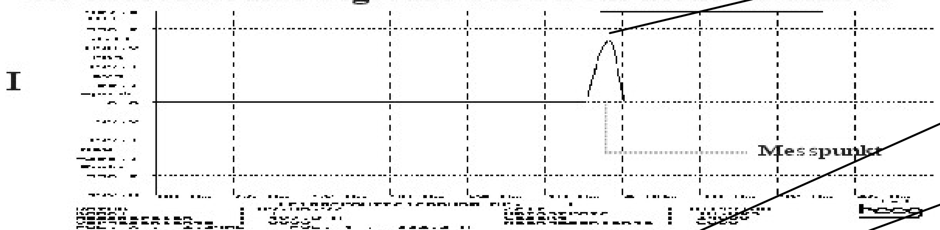
- Here are missing a piece of a grid voltage time area.
- Test with an 1,5 kVA toroidal transfo at 230V.
- A 5 msec. during loss of voltage leads to tripping of the B 25A Lineprotectorswitch,
- Because of transfo saturation an current peak of 250A high occurs.

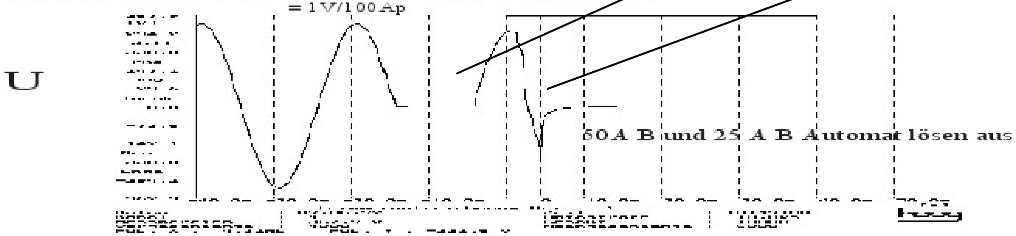
- Voltage drops with this shape and similar loss of voltage time area, was from EMEKO to be measured onto industrial grids.
- And therefore it is a good practice to test transformers or power supplys with a higher deficit of voltage time areas up to 10 msec. in one half wave.



A 10 msec. voltage drop of one half wave leads to a catastrophal effekt for the transformer and the fuse.

Einschaltstromstoß-Test verschiedener Trafos im Leerlauf.
Prüfgerät: IRST0, Inrush-Stimulator, Zuleitung mit 10m mit 16qmm an Hauptvert. und insges. 2m mit 6qmm zu IRST und Prüfling.
Einschaltverfahren: schlechtester Netzausfall Typ
Trafotyp: 1,5kVA Ringkern Trafo Lieferant: Induktor
Leerlaufstrom: 0,1Aeff Netzspannung: 234V
ges. Netzimpedanz: ca. 0,3 Ohm incl. Absicherung von: 50A NH 00, + 50A B, + 25 A B Automaten
Modalitäten: an 230V Wicklung des Prüflings angeklemmt.
Meßergebnis des max. Einschaltstromstoßes: 332 Apeak, der 25A Automat begrenzt den Strom nicht zusätzlich





Prüfaufbau:

die beiden Automaten vermindern den Stromstoß nur um 7 Ap.

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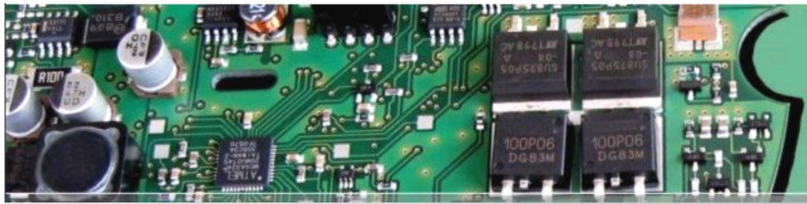
B0070.pcx u. B0071.pcx
irst0057.cdr

- Thats the worst case for a transfo.
- Inrush current peak of 332A peak.
- 10 msec. Voltage-Dip
- An B 25A and a B 50A lineprotecting-switch are tripping together.
- Measured with an 1,5 kVA toroidal transfo at 230V.
- This simulation procedure is applicated to test medically equipments, also with transfos inside and the fuses shall not trip.



Since 2007 the test with voltage dips is the duty.

- Voltage-Dip´s, are the missing of a full voltage half wave, or parts of it or longer during deficits.
  .
- Concern to EN 60601-1-2, and the drafted EN 61000-4-11, Electromedically equipments, including IT net transfos, must be tested with voltage drops. See table at right, with 95% Ur decay for 0,5 Perioden.
- Transfos are running into saturation if the voltage returns, because of getting two times of an halfwave with the same polarity. That is Leading to a higher inrush than with normally switch on at the worst case point.

Extract of EN60601-1-2, S.69

60601-1-2 © IEC: 200X-YY -69-

A per phase, deviation from the requirements of Subclause 36.202.1 j), *Compliance criteria*, is allowed at the IMMUNITY TEST LEVELS specified in Table 207, provided the EQUIPMENT and/or SYSTEM remains safe, experiences no component failures, and is restorable to the pre-test state with OPERATOR intervention. Determination of compliance is based upon performance of the EQUIPMENT and/or SYSTEM during and after application of the test sequence. EQUIPMENT and/or SYSTEMS that are not LIFE-SUPPORTING and for which the RATED input current exceeds 16 A per phase are exempt from the testing specified in Table 207.

2. EQUIPMENT and/or SYSTEMS are allowed a deviation from the requirements of Subclause 36.202.1 j), *Compliance criteria*, at the IMMUNITY TEST LEVEL specified in Table 208, provided the EQUIPMENT and/or SYSTEM remains safe, experiences no component failures, and is restorable to the pre-test state with OPERATOR intervention. Determination of compliance is based upon performance of the EQUIPMENT and/or SYSTEM during and after application of the test sequence.

LIFE-SUPPORTING EQUIPMENT and/or SYSTEMS for which this allowance for a deviation from the requirements of Subclause 36.202.1 j), *Compliance criteria*, is used shall provide an alarm, complying with applicable international standards, to indicate cessation of intended FUNCTION.

Voltage test level % U_T	Voltage dip % U_T	Duration Periods
< 5	> 95	0,5
40	60	5
70	30	25

Table 207
IMMUNITY TEST LEVELS for voltage dips

Voltage test level % U_T	Voltage dip % U_T	Duration Seconds
< 5	> 95	5

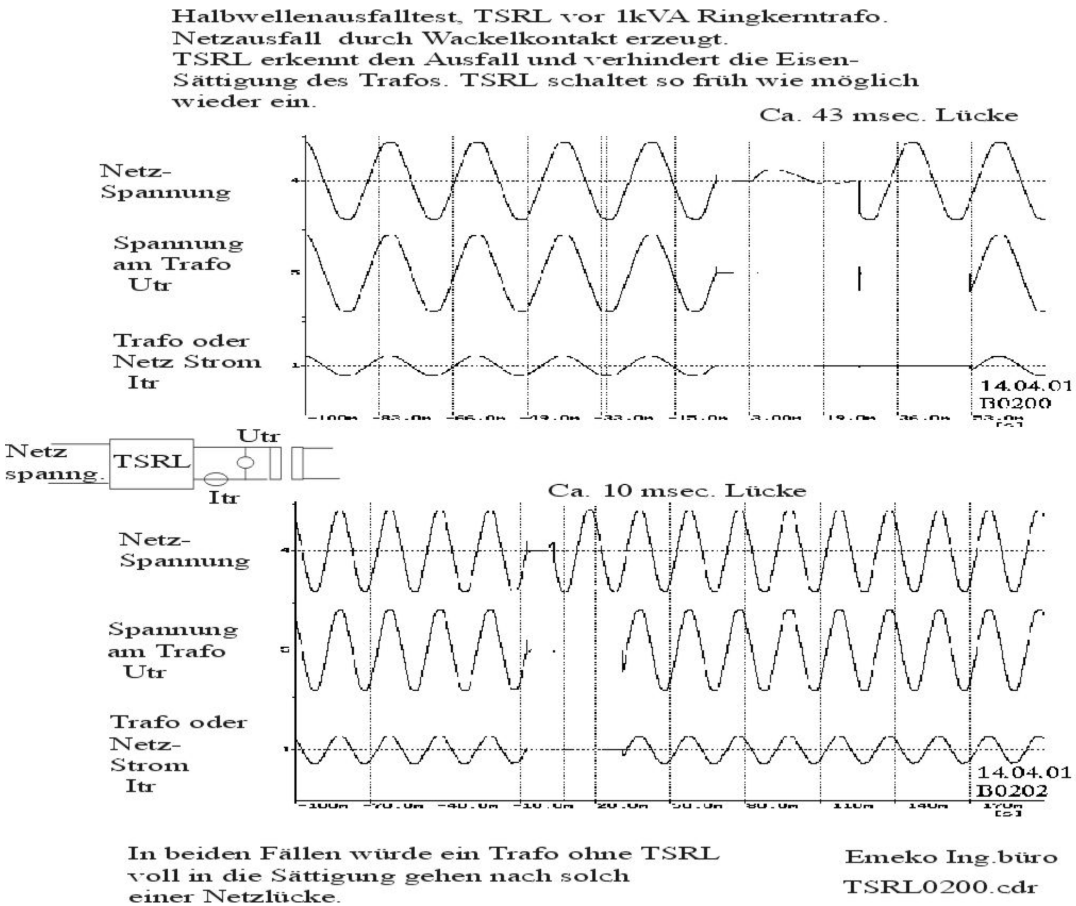
Table 208
IMMUNITY TEST LEVEL for voltage interruption

b) Tests

The test method and equipment specified by IEC 61000-4-11 shall apply with

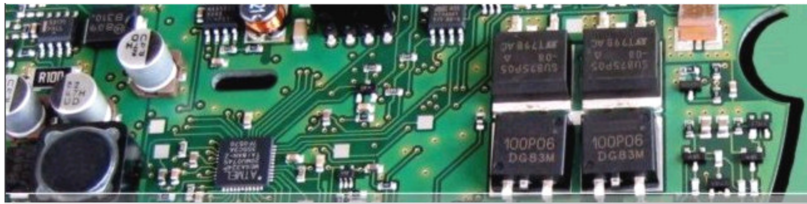
Effect of voltage drops after using an TSRL.

➔ No inrush effect of voltage drops **if a TSRL is connected to the toridal transfo.**



The fast switch off reaction onto the voltage drop and the intelligent, calculated, switch on of the TSRL, protects the transfo from saturation at the return of the grid voltage.

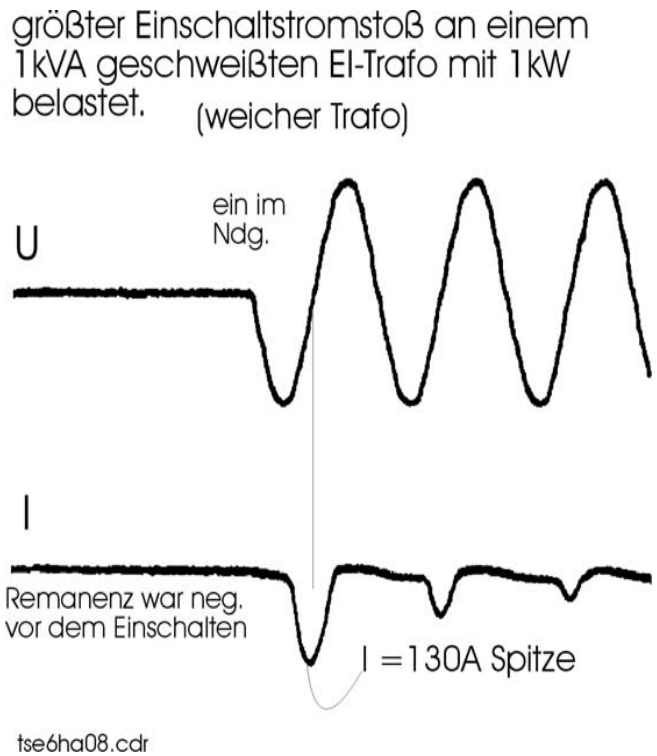
Fast restart with full on switching, with only the nominal current amplitude.

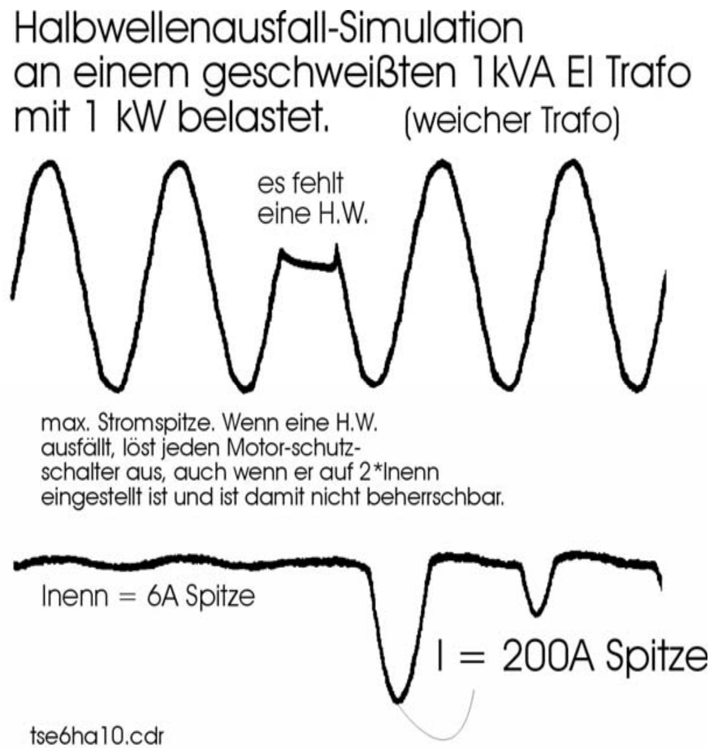


Behaviour of an low-inrush-like Transfo with considerable losses.

(Welded EI-core, 1kVA measured at nominal load state.)

Difference between left an right = 70 A peak= **35%**





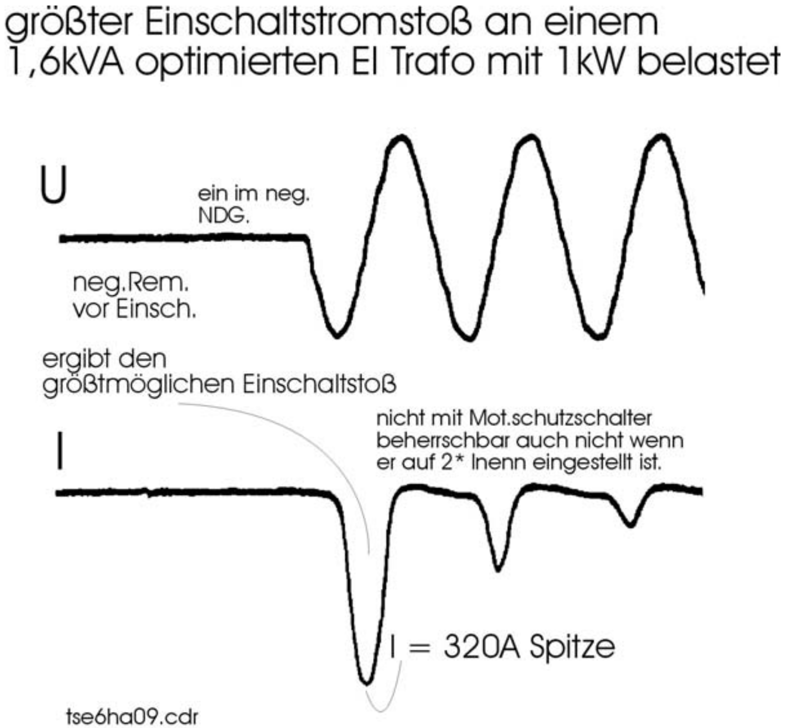
After a voltage gap he is about 35 % higher

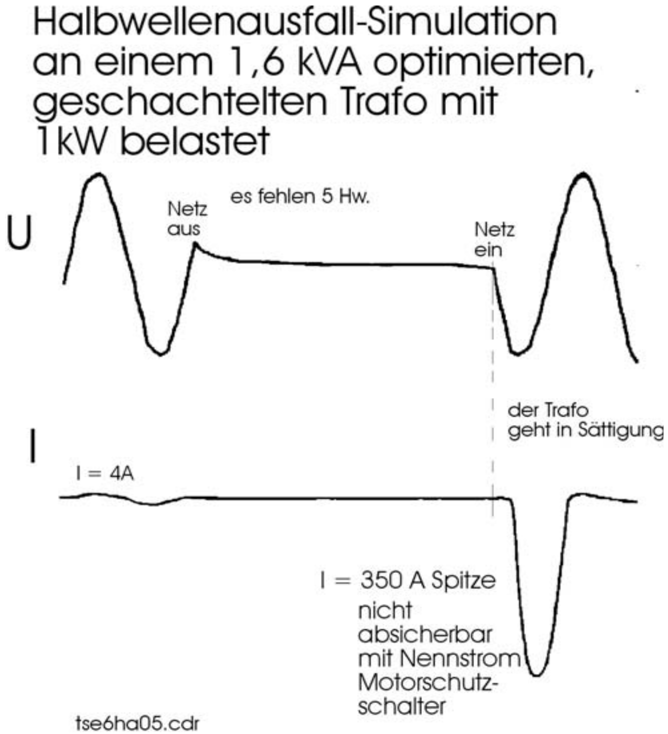
The normally inrush current peak is low.

Behaviour of an high-inrush-like Transfo, with low losses.

(1,6 kVA EI-core-stacked, measured with nominal load.

Only a little difference between left and right = 30Apeak, **= 8,6%**





The normally inrush current peak is high.

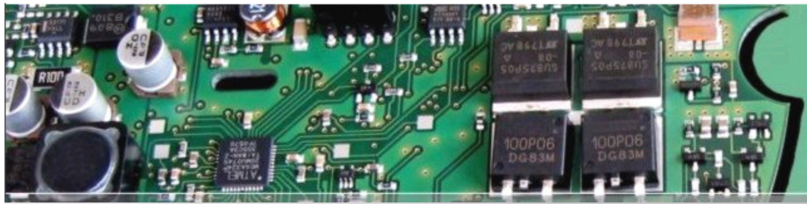
After a voltage gap the inrush is about only 8,6 % higher.

consequence from the test with voltage gaps:

Why low inrush transfos with higher losses shall to be used in future?

- Transfos with low inrush behaviour are bringing no advantage, if voltage drops are to be considered. (Also if a voltage drop is only for test in duty.)

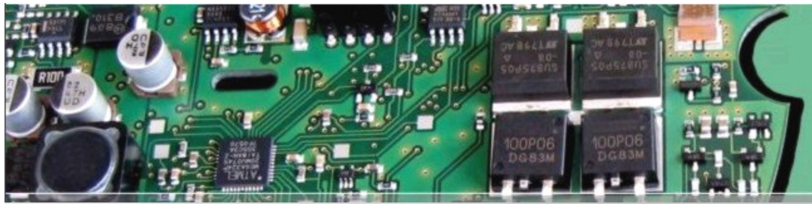
- Then are better low loss transfos is to be used, which indeed having high inrush current peaks,
- but together with an TSRL having no inrush current peaks, also if voltage dips occurs.
- And energy saving is gratis.



Transfo is not similar transfo.

Why occurs this different behaviour between soft and hard transfos, like showed before in foil 39 and 40?

- The different shape of the hysteresic loops is the cause. Reason for that is the different shape of the iron core types. See the following foils.
- Generally is true: If a short voltage gap of only 10 msec. occurs, the magnetisation B onto the Hysteresic loop is not running back to the stable rest point of the remnance, like after a longer pause. Then if the voltage returns after 10 msec., the B ist sitting on a higher value of the magnetisisation. Following is a higher value of time area available to drive the Iron into a higher value of saturation, following with an higher value of inrush current.

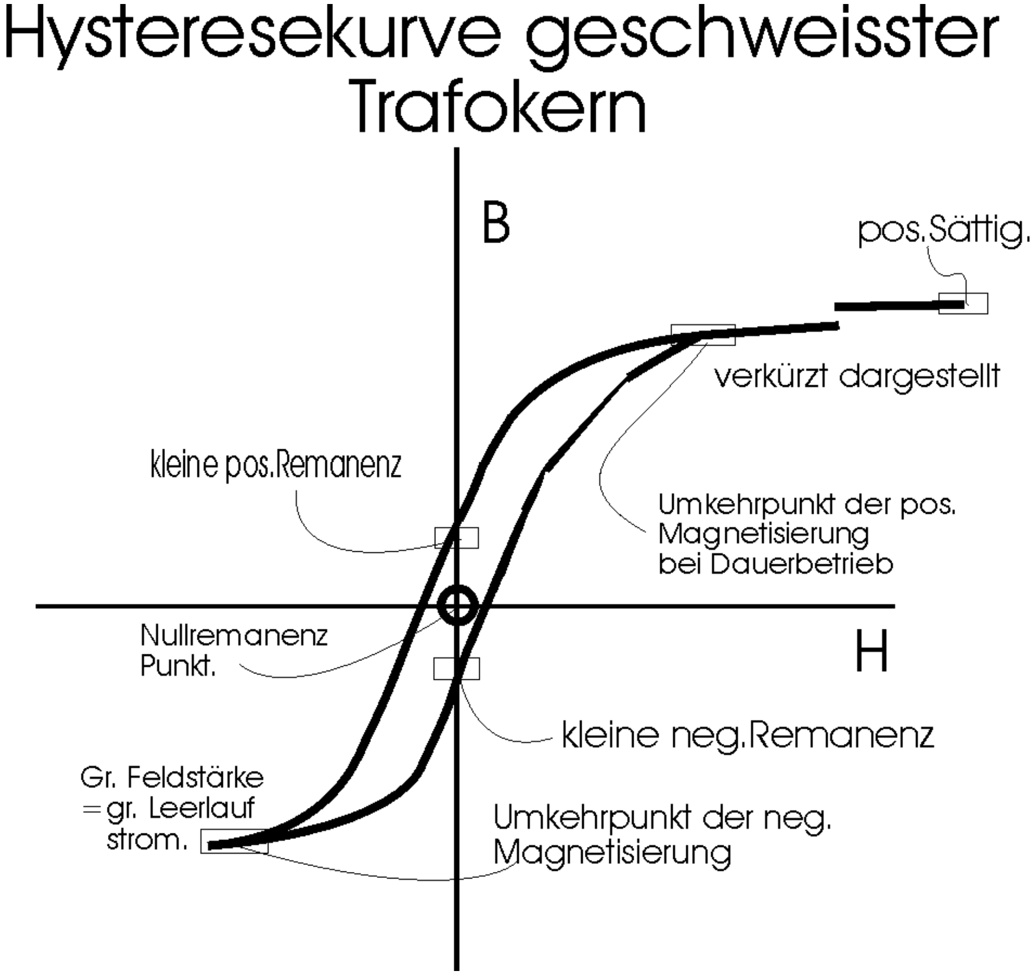


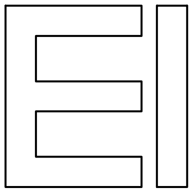
Hysteresic loop of a transfo with a welded core (EI core with considerable air gap)

➔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.



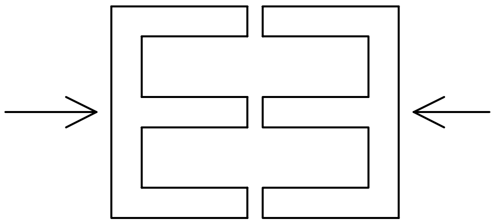


(EI core transfo)

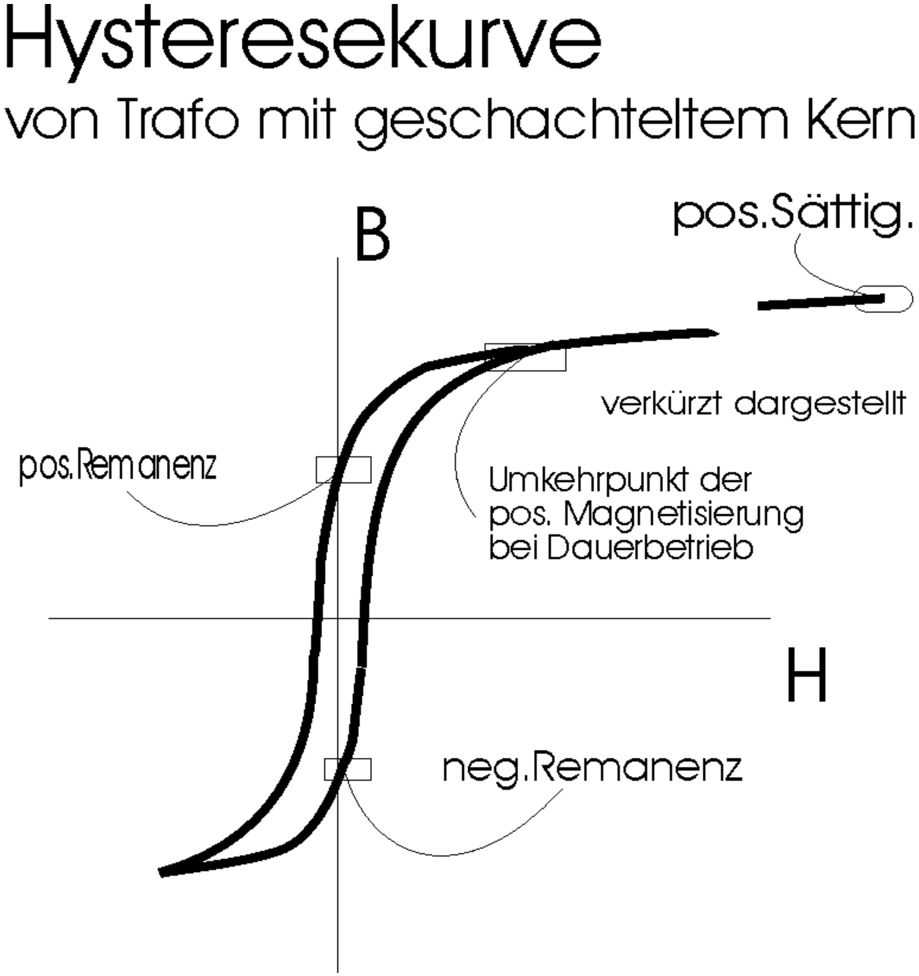
Hysteresic loop of a transfo with a stacked core (EE core with less air gap)

➔ 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

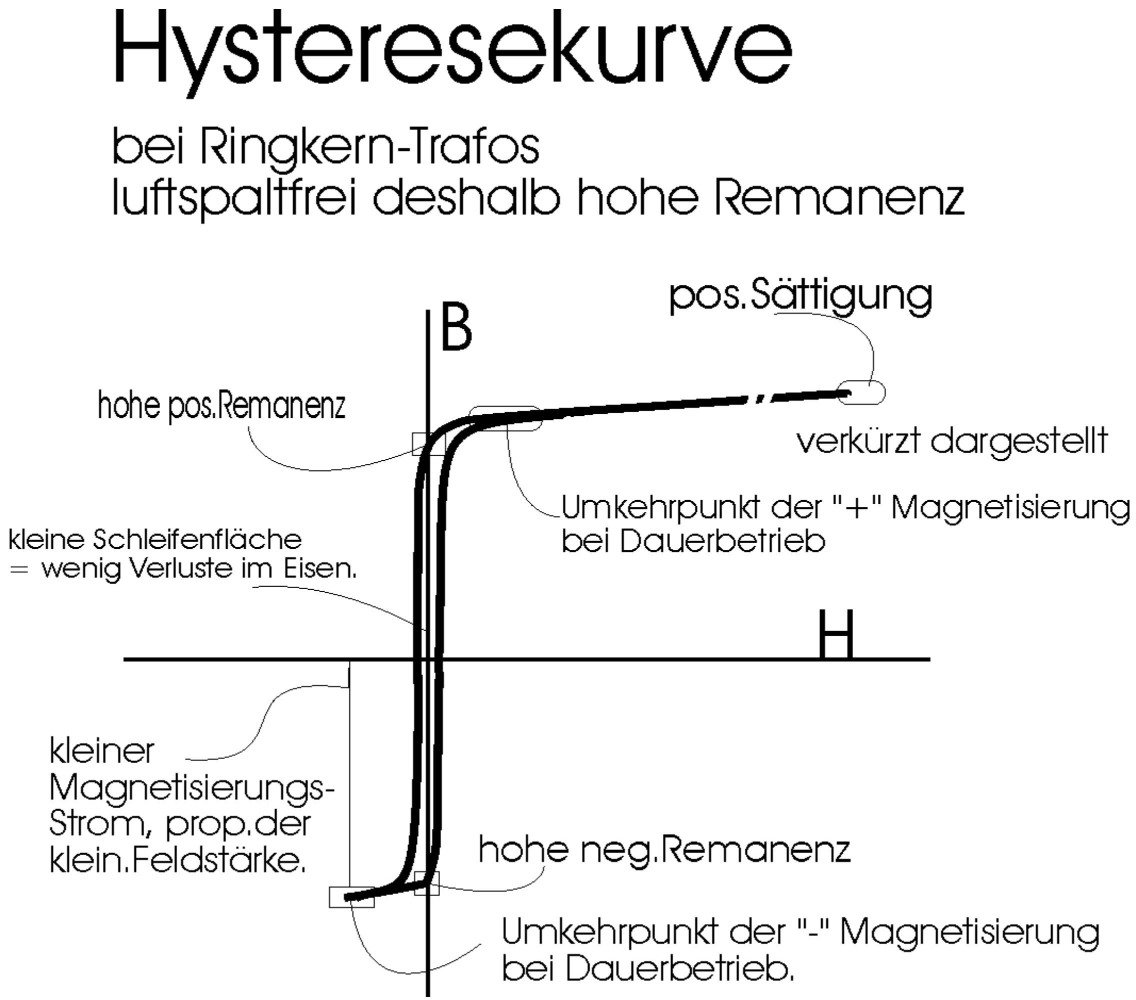


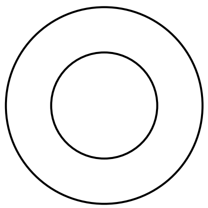
Stacked Laminates shifted with alternating sides.



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

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.

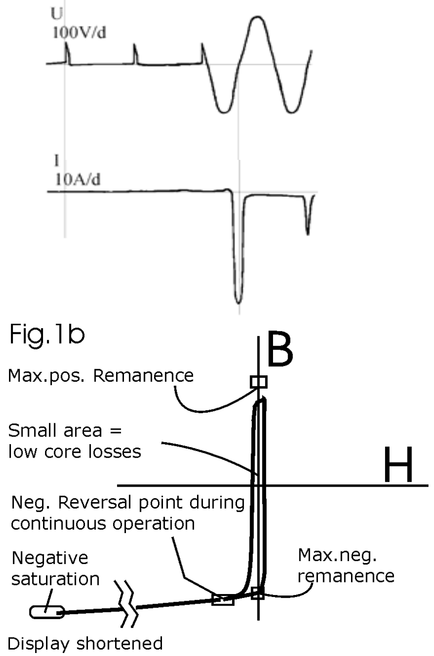
- (FSM can deliver also TSR without a trim pot, with per Software fix adjusted Pulses, for a predefined transfo type.)

Adjusting samples with a TSR.

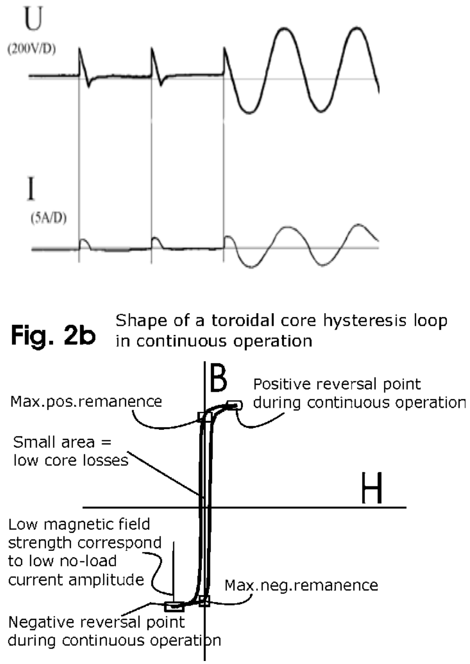
Sample for an Toroidal core Transfo.

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

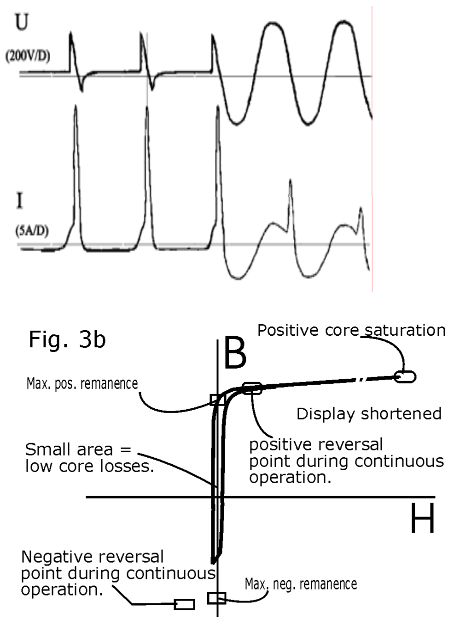
The current-answer of the transfo, tells us what´s happen inside the core.



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.

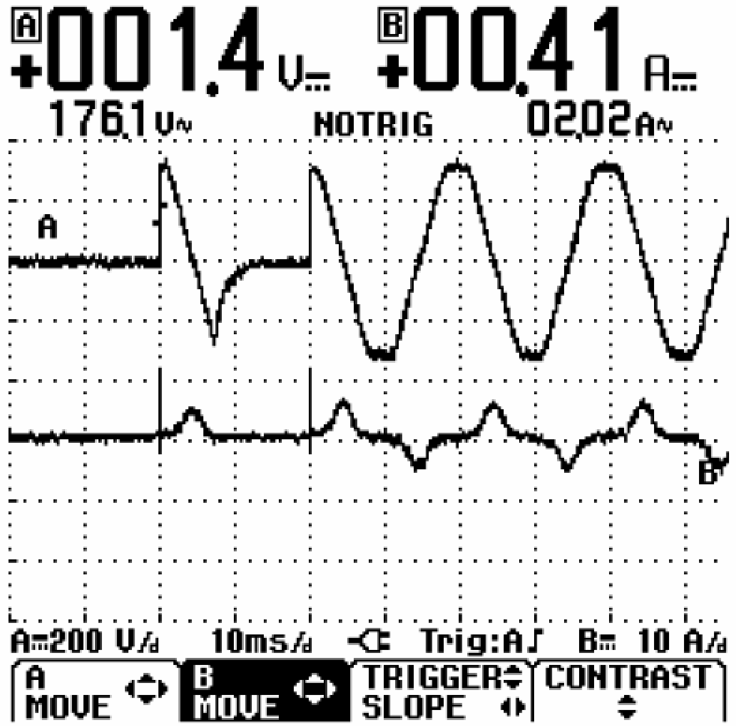


To strong premagnetised.
+25A current needles
at fully switch on.
A harmless case.
Trim pot on 9 o clock 30.

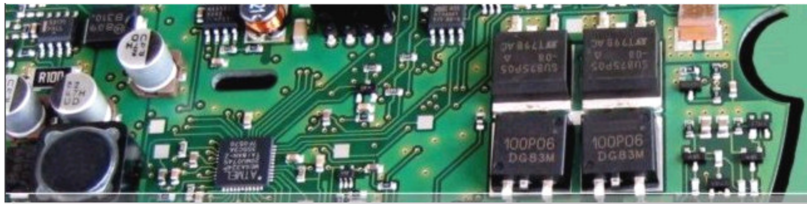
TSR-Switch on samples with different transformer types-1.

- The unloaded 0,8 kva Magnetron-Transfo, he has an considerable air gap, to see on the high no-load current of 6 amps peak. He needs voltage time areas of 4 msec. abroad of each.
- Two Pulses are enough, because the starting remnance point is sitting nearly the zero remnance point.
- **The Trim pot is adjusted on 17 o clock.**

- Such and only such transfos can to be started without an high inrush current peak with peak switching solid state relays. That correspond then to a 5 msec. Pulse following with a low inrush current peak, not showed here.



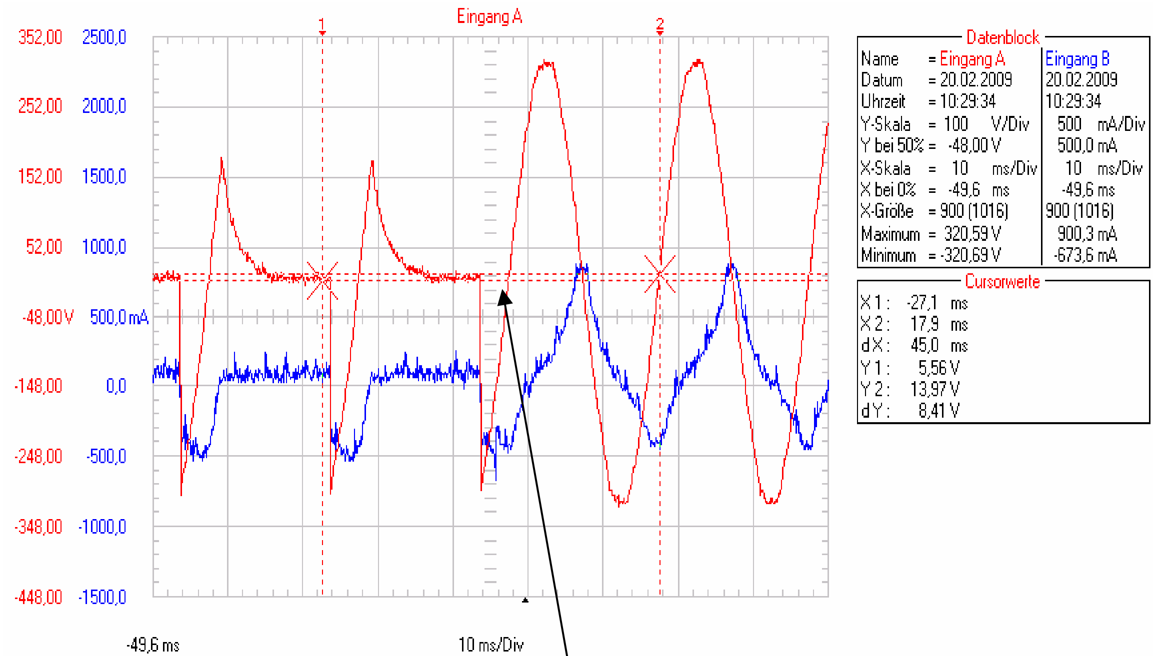
tsrmagnetron.fvf   Emeko Ing Büro Freiburg M.Konstanzer, TSRL schaltet Magnetrontrafo mit 800VA im Leerlauf ein, (großer Luftspalt) Poti auf 15Uhr= 4 msec. Spanngs.zipfelbreite. Nur mit TSR-Prinzip ist einschalten mit dem Leerlaufstrom möglich.



EMEKO and

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

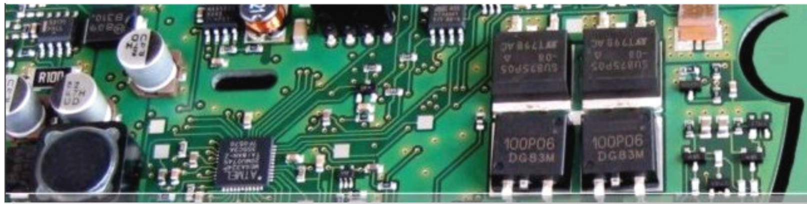
- The unloaded 1 kva EI-core-Transfo with a stacked core, with a small air gap, needs some voltage Pulses with 3 msec. broadness.
- 8 pulses ar needed, because of the high starting max. remnance, to transport the B to the opposite point.
- **The trim pot is adjusted on 13 o clock.**



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

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.

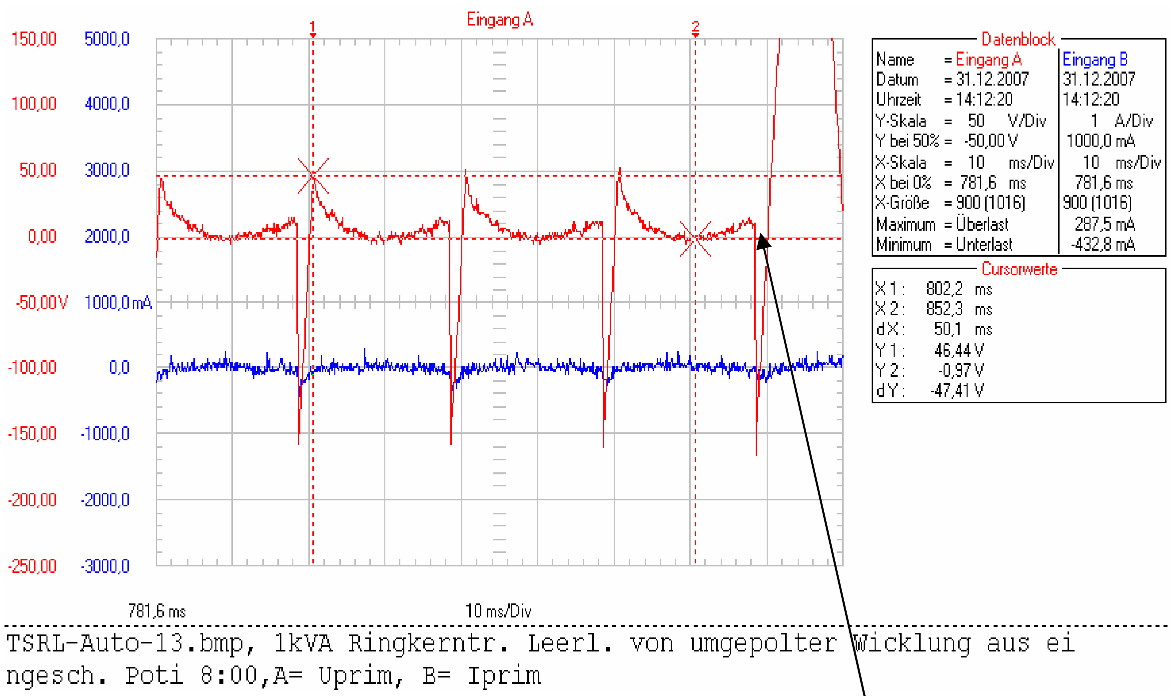


EMEKO and

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.

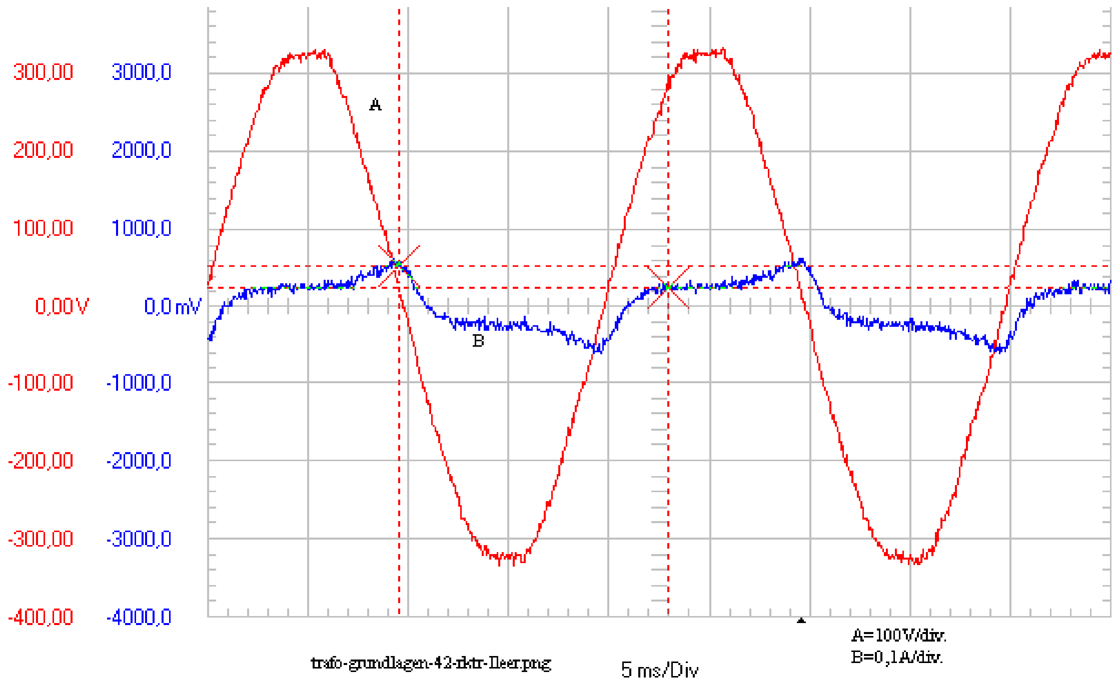
Advantages from an Toroidal core Transfo:

➔ 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.*



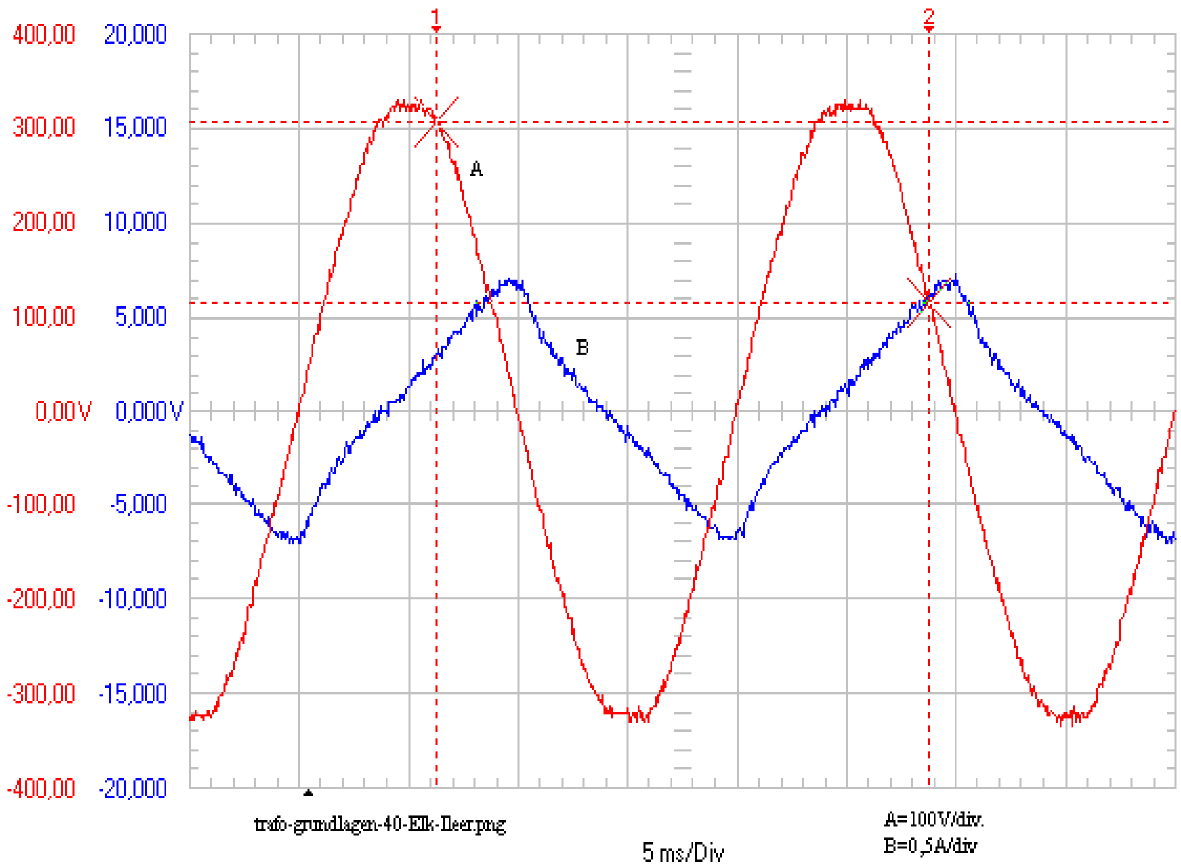
You cannot say, that the off-load current, blue curve, has a lag of 90 degr. to the voltage. In the middle of voltage curve he is even in phase.
In the most of literaturs is the off-load current showed as a sinusodial shape who has a lag of 90 degr. to the voltage, and that is a fault.

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.



Pause

Now follows something about the physic inside the transfo.

- The most part of the physic is already declaired with the voltage time areas and her effect of the magnetisation inside the transformer core.
- But no fear, the following declaration happens nearly without formulas, because with the effect of the voltage time areas you understand the most of the transformer physic.
- Think on: The voltage time area transports the magnetisation in the core along the hysteresic loop, and the off-load current is the answer from the transformer to that transportation.

Physic understanding without formulas.

- Formulas are describing what happens with a theorie.
- Often they are only aproximations to the reality.

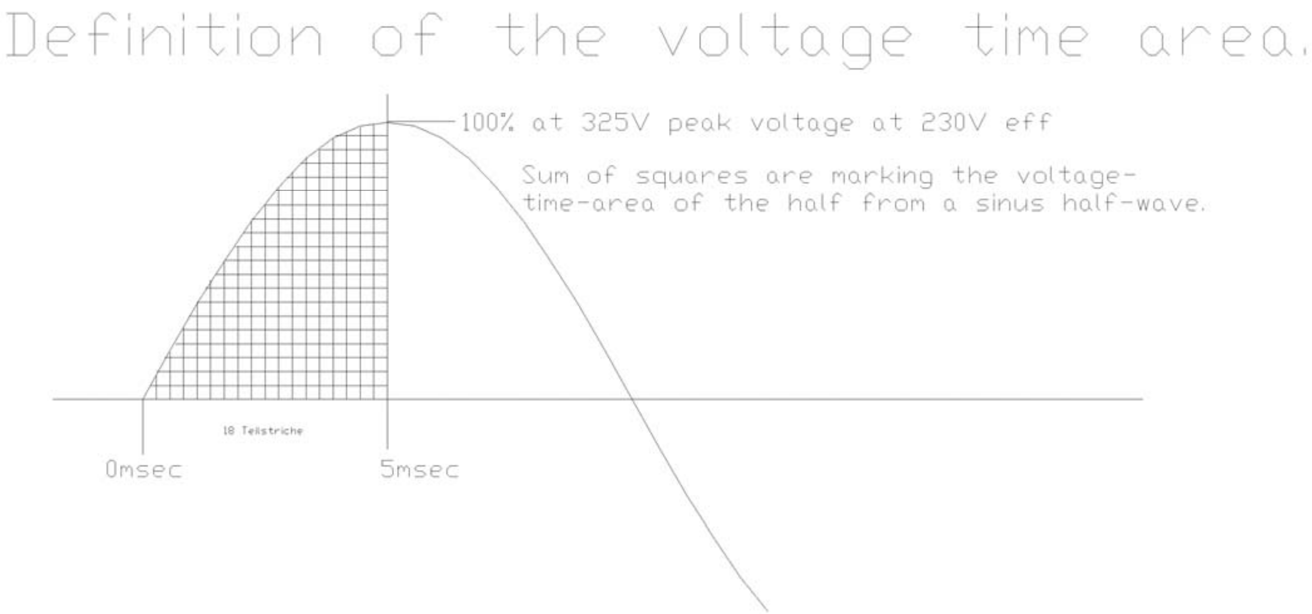
- Pictures and graps are mostly showing better and are easyer to understanding, what happens.
- They are more descriptive than formulars.

- At the transfo shows the oscilloscop measured off-load current of the primary coil what happens to each point of the time, in conjunction with the Voltage curve at the primary coil.

On the next foils you find a declaration of the following comprehensions.

- Hysteresic loop course in the air, in iron, in different shapes of transformer cores.
- Remnance.
- Core losses.
- Air gap in the core.
- Saturation in the core.
- Induction.
- Inductionvoltage, counterinductionvoltage.
- Off-load current Izero, Fieldstrengh H.
- Magnetflow Phi.
- Magnetflow dense B.
- Magnetomotive force, magnetomotive resistance, magnetomotive voltage.
- Voltage time area, voltage push.
- Premagnetising with small voltage time areas.

What are voltage time areas???



Voltage time area is an old notion, already used from Michael Faraday. He says to it voltage push. The voltage time area moves the B along the hysteresic loop up an down.

- The sum of the small squares above, marks the voltage time area of the half from a sinussodial voltage half wave. But also each other part area of the voltage on any position of the time axe is an voltage time area.
- The voltage time area from a sinussodial voltage half wave at 230V and 50 Hz has about 2,0 Voltseconds. A Transfo for 230V is calculated for that. His magnetisiation runs trough this application of the voltage time area from one to the other end of the hysteresic loop.

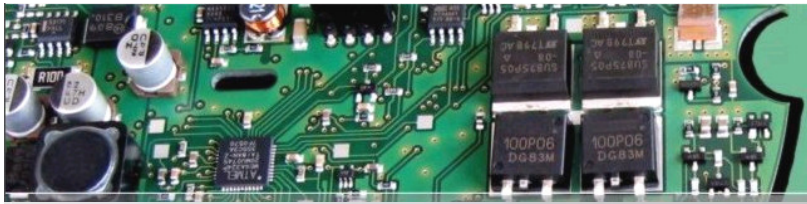
Transformer without a remnance are rarely.

At a Transfo without a residual Magnetisation, the so called Remnance, stays the magnetisation after switch off from the primary voltage not at the point of the hysteresic loop at this point of time. He runs of the shortest way to the symmetrically middle of the loop, to the B = 0 and H = 0 Point.

Transformers without a iron core have no hysteresic loop and no remnance.

Transformers with Iron cores without a remnance have large air gaps and are not economic for 50 HZ Transfos, because an air gap stores energie in each voltage half wave and send it back to the begin of the next opposite half wave to the grid. It´s the so called inductive current that must be compensate to reduce the grid losses.

Only with such transfos can peak point switching relays deal. D´ont care of the starting direction and voltage polarity, the starting voltage time area from an peak switching is always right to bring the magnetisation to the end of the hysteresic loop, because the Remnance is near zero.

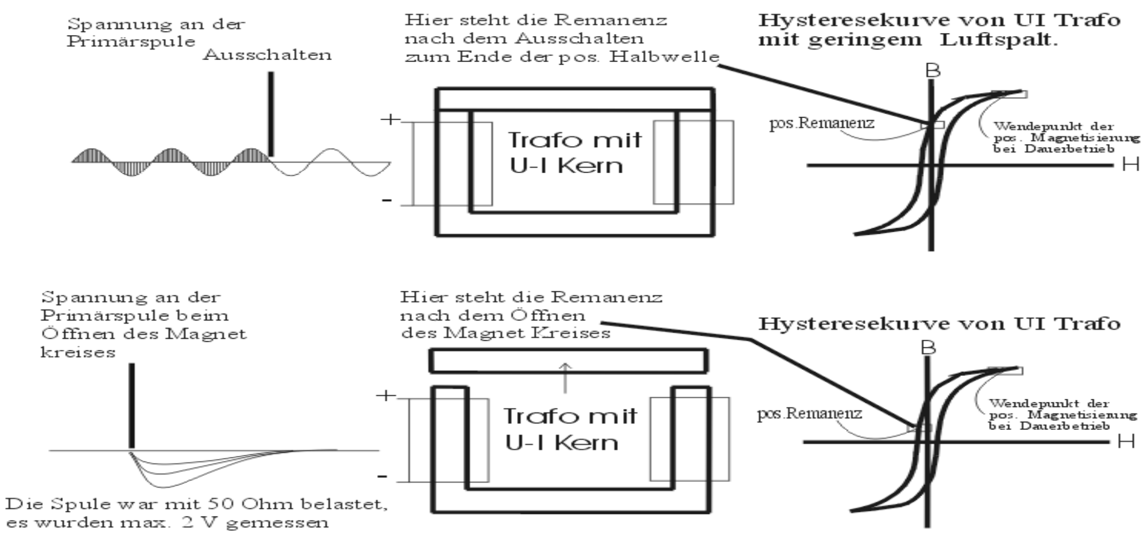


What is Remnance? An Expiriment to learn.

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.

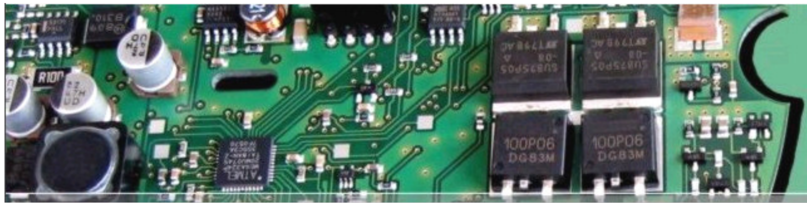
Iron Core Saturation

- 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**..)

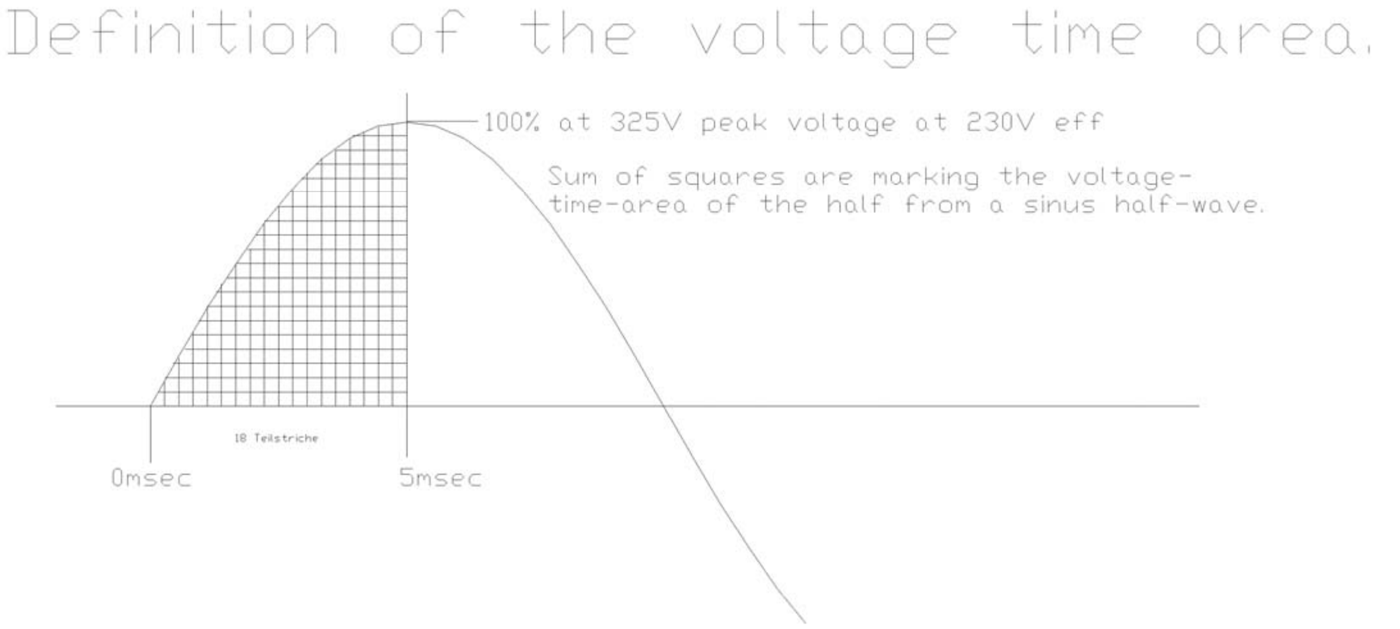
What is a „voltage time area“??

- 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.

What happens in the elctromagnet with dc-1.

For the calculation of the force in the airgap of an electromagnet is the current important!

At an DC Voltage feeded electromagnet without an iron core **is the current** not suddenly flowing with his end value in the same moment if the voltage is applied. (With a core into the coil the current raises much slower.)

He rises from Null until the endvalue I = U/R, correspond the function off the time Tau = L/R.

The magnetisation is driven from the voltage-time-areas. She is an rectangle at dc voltage.

After reaching the current end value, the longer time of the voltage-time–area has no more an effect, the current is limited from the coil resistance and no driving voltage is on the „inner coil“ after that.

What happens in the elctromagnet with dc-2.

Also at an DC Voltage feeded electromagnet with an iron core is the current not suddenly flowing with his end value in the same moment if the voltage is applied.

He rises from Null until the endvalue I = U/R, correspond the function off the time Tau = L/R. The L is much higher than at the coil without an iron core.

The magnetisation is driven from the voltage-time-areas. She is an rectangle at dc voltage.

Behind the reaching of the end of the current value, the longer time is not useful, the force has also his end value.

What happens in the elctromagnet with ac-3.

While the saturation in the core is not reached and the coil runs voltage dominated and the current is also not limited, on can say, that at the connection of a coil with ac voltage, the voltage-time-areas are responsible which drives the magnetisation around the hysteresic loop.

The force $F = (B / K)^2 * A$. You cannot find a parameter for the current in the formula. Via the hysterescic loop he can be found.

The current is the projection of the magnetisiation on the horizontal axe of the hysteresic loop and also an reaction to the voltage-time-areas.

This underlines also the sight with voltage-time-areas.

Whats about the no load current?

The Magnet. Flow Theta = I * N, has the Dimension [A]
Or Theta = H * L, Field strenght times Lenght L oft the fieldlines. Dim. [A/cm * cm]
H * L = I * N, shows, that the current I depends from the field strenght H, if L and N are given for a transfo.
I * N / Rm = B * A , magnet.flow / Magn. resistance. = Magnetflow. Dim. [Vsec.]

Attention of missmatch: I does not mean the load current, it means only the off load current I, not transferred to the secondary side.
The field strenght H inside an Transformer core stays the same opposite the no load state, if he is connected to a load at the secondary side.
The magnetisiation runs under load on the same shape of the hysteresic loop, like in no load state.
One more time to say: The no load current is only the answer onto the things happen from the voltage-time-areas proceeded to the transformer. Thats true for all shapes of transformers, load states and Hyteresic loops.

Rule of Induction-1.

The rule for Induction, Ut = dphi / dt, is responsible for the physic in the Transformer. To generate voltages into all coils or windings.

But also the counter EMF is an effect in the primary coil. Otherwise the off load input current for example would be 230V / 0,3 Ohm, (the Cu-resistance), in the same hight like the inrush current.

In truth is the voltage, which drives the no load input current much lower. She is the input voltage minus the self induced counter EMF voltage.

To self imaging the counter EMF voltage is unconvenient. This voltage is not to be measurable. She exist as an model.

Rule of Induction-2

If you put into the following Furmula the noload current, then the result fits to the Induction formula.

The magneticvoltage Teta = I * N. And B * A = is the magneticflow Phi.

I * N / Rm = B * A = magneticflow Phi.

Rm is the magnetically resistance, A the core area, I the noload current, N the count of windings.

In Analogy to the Ohmic law: U / R = I. I*N = magn. voltage. B*A = magn. Current

Into the magn. Voltage = I * N , is the electr. current into

and in the magn. current = B * A, is the electr. Voltage into.

It is simply opposite like at the Ohmic Law.

You can understand the physically function of the transformer also with the effect of the noload current, if you are using the law of Ampere.

But you need therfore the shape of the hysteresicloop, to get the B and this is complicated.

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.

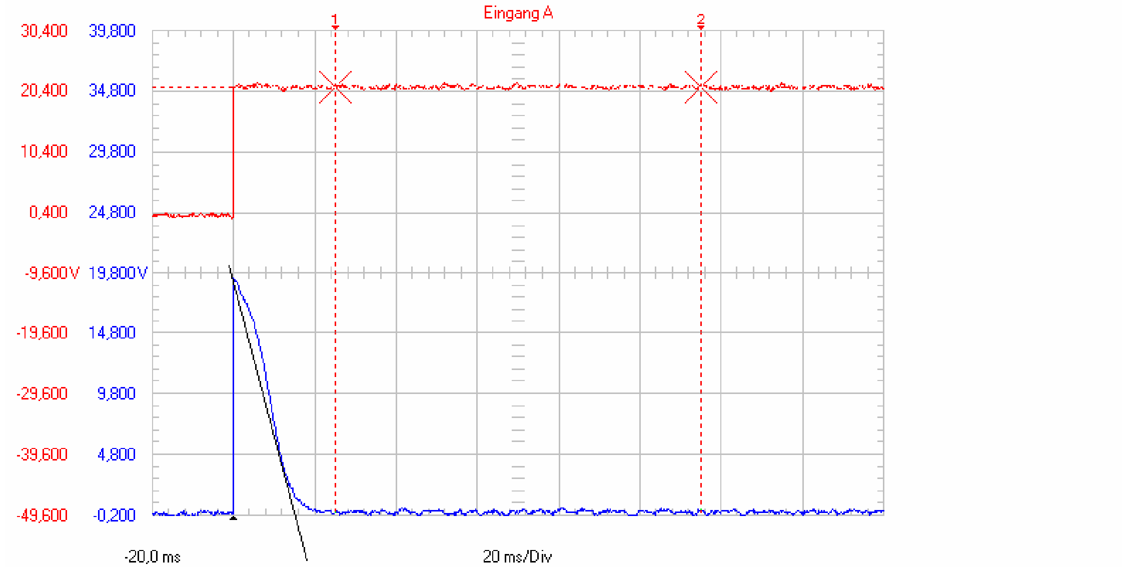
A Practicaly demonstration for the sight with voltage-time-areas.

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.

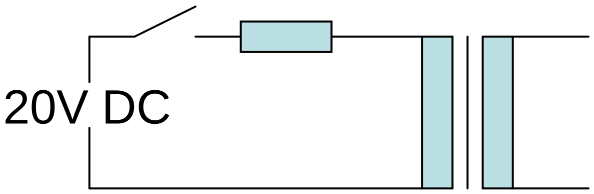
Precondition: Here is to seen at a 1kVA toroidal core, how does immediatly after switch on, to the core is going into saturation, because the core will not be changed in his magnetisation from the red curve.

- 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.)

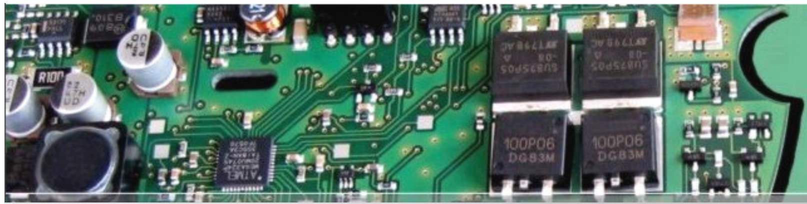


Trafo-Grundlagen-18.bmp, 1kVA Ringkerntr. v. pos Rem. aus mit +20V Sprung, A= Uangel. B= Utreib nach Rv von 100 Ohm.

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

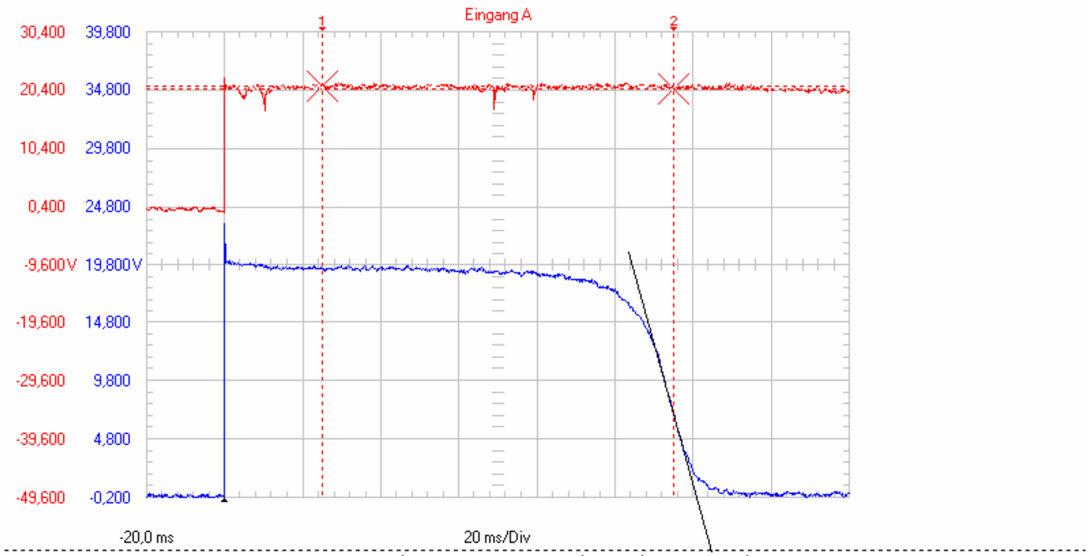


See also the shape of the hysteresic loop from the toroidal core.



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

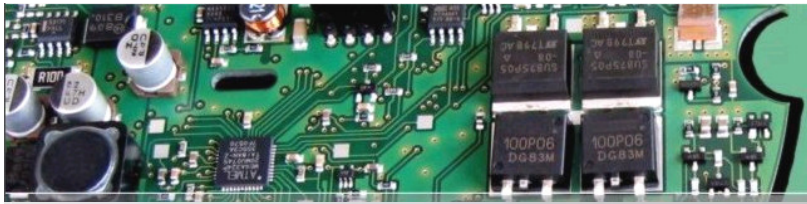
- The red curve shows the same test voltage like in foil 76 before, see also schematic.
- The blue curve shows the voltage directly at the primary coil, measured like in the foil 76.
- The blue curve falls much later down, than in the foil before, because the core goes later into saturation. (At 120msec.)
- 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.

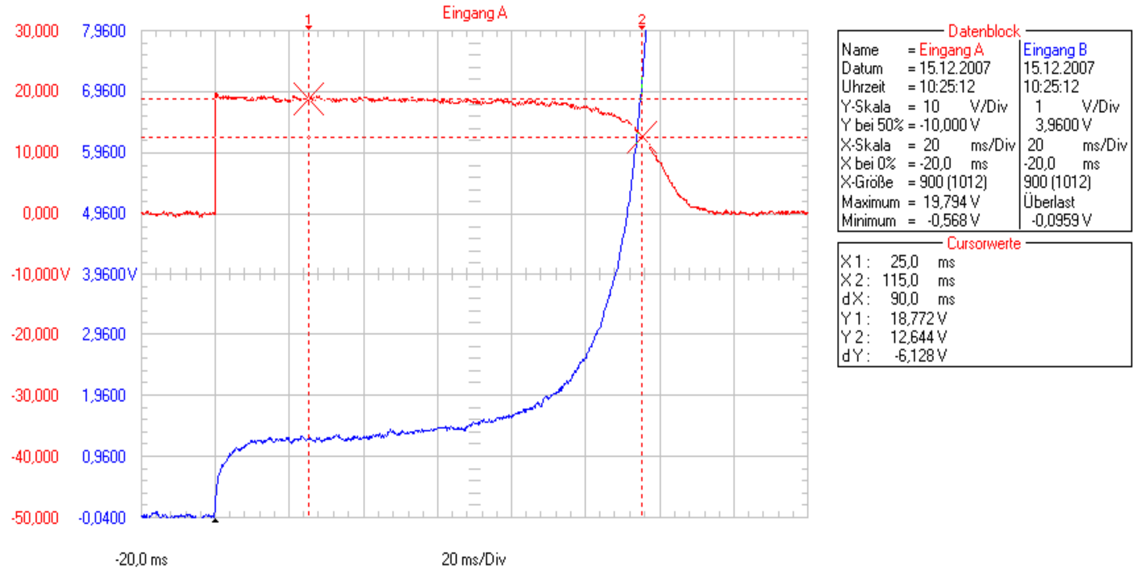
Korrektur : wie Bild 18

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.



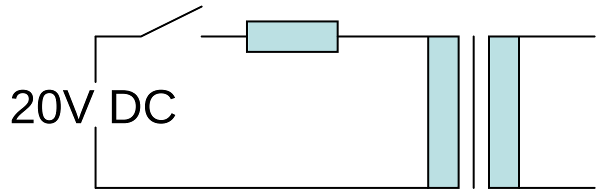
Induction happens only as long as the transformer core is not saturated -3

- 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.

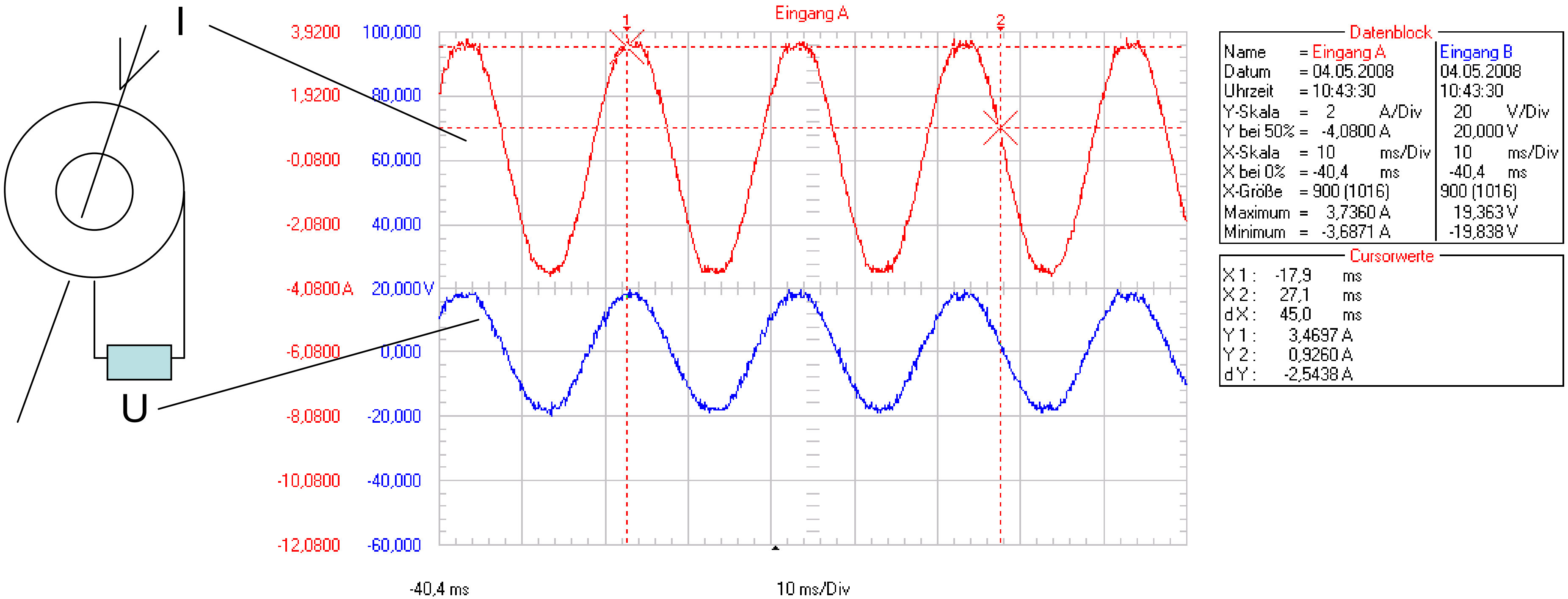


Trafo-grundlagen-17.bmp, Ringkerntrafo 1kva, von neg. Remanenz aus mit pos.kleinem Sprung. A=Utreib, B= U an Rv mit 100 Ohm, also 10mA/div

Like foils before only with other measuring points.

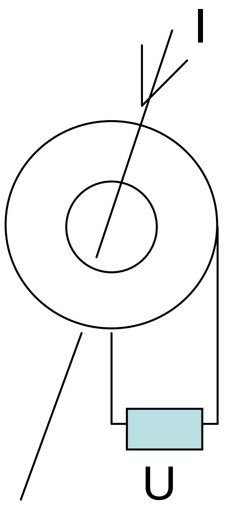


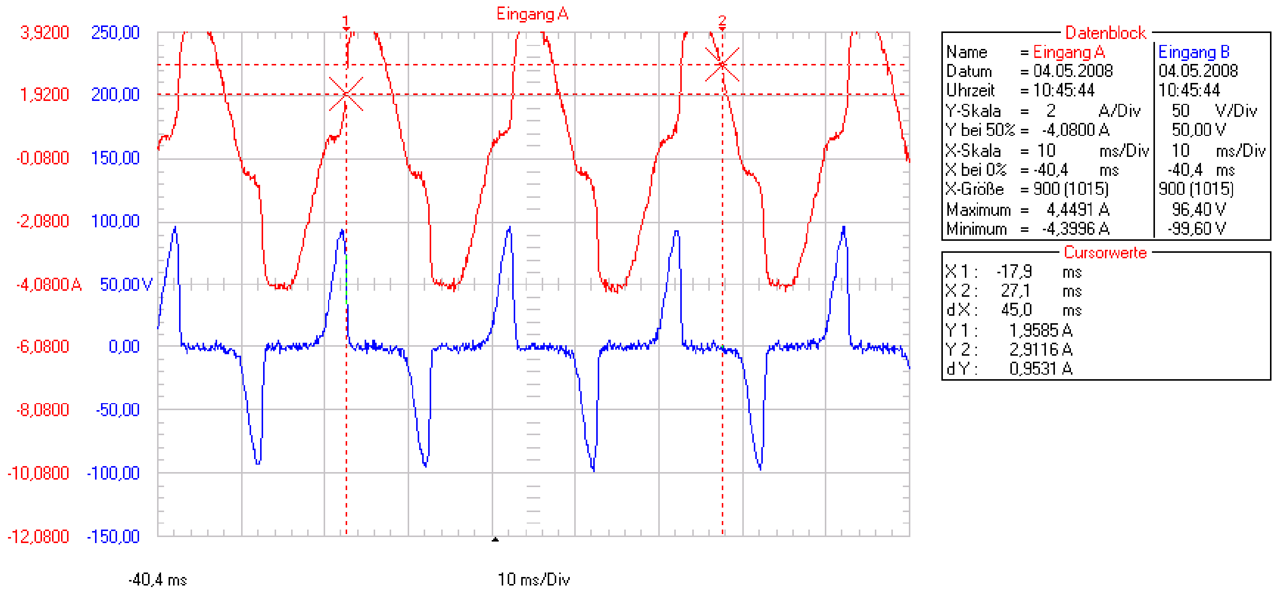
To compare: Test on a current transformer-1.



- Current transformer VAC ZKB 465/501-03-160 A3 , Ü=50A / 0,05A, at 200 Ohm load.
- The transducer can carry 50A and is with this current not to be saturated at a load of 200 Ohm.
- The input current here is 3,5 A peak. At a 5k Ohm load the output voltage is than 18V peak. (3,5mA * 5000 V/A)
- The outputvoltage follows truly to the input current otherwise the load ist to high, (not 200 Ohm). The voltage time area in this example has an amount of 0, 130 Vsec. (Not to much for this core.)

To compare: Test on a current transformer-2.

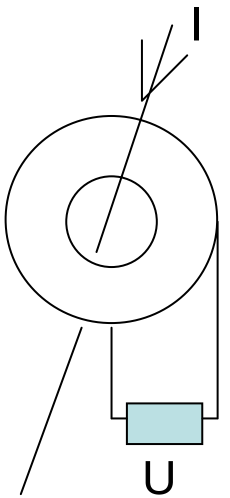


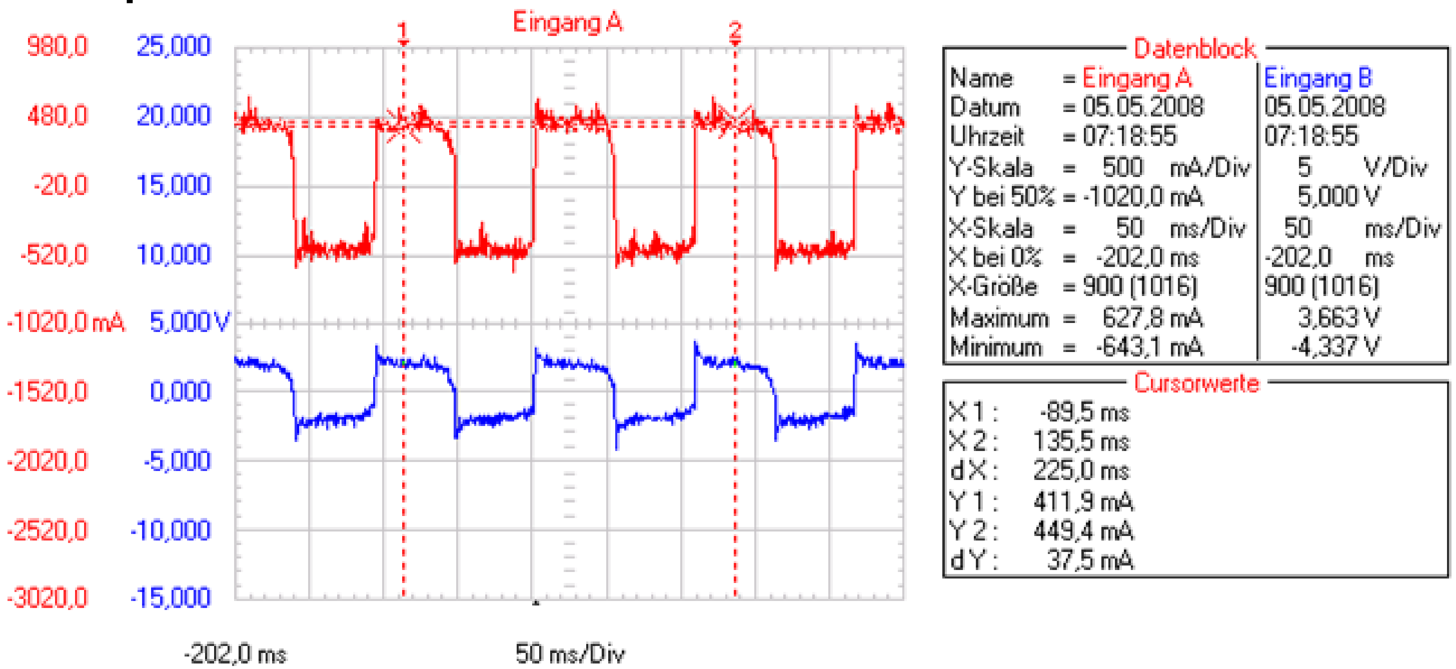


Stromwandler-test-6.bmp, wie 5 jedoch keine Bürde, also offen. Starke Sättigung. Eingangsstrom wird beeinflusst.

- The input current is with 3,5 A the same as before. Without an load resistor the outputvoltage has increased and brings the core in a short time after the begin of each voltage half wave into saturation. The current has the same amplitude like in the foil before, but he is influenced from core saturation, (Counter EMF.)
- Thats a nice evidence for the effect of the voltage-time-areas with a to large amount does saturate the core. Here 0,2 Vsec.. Between 0,17 and 0,2 vsec is going the core into saturation. For the truly transfer of this signal is a core needed with a capability of 1Vsec. (Then the blue curve has no saturation degradation and is a sinusodial curve. This tested core here is to small or the load is to high ohmic.)

To compare: Test on a current transformer-3.

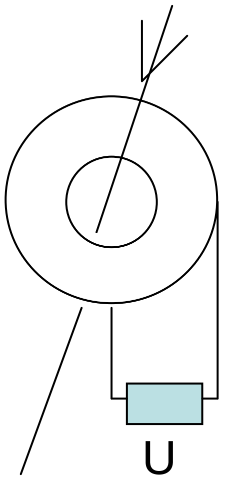


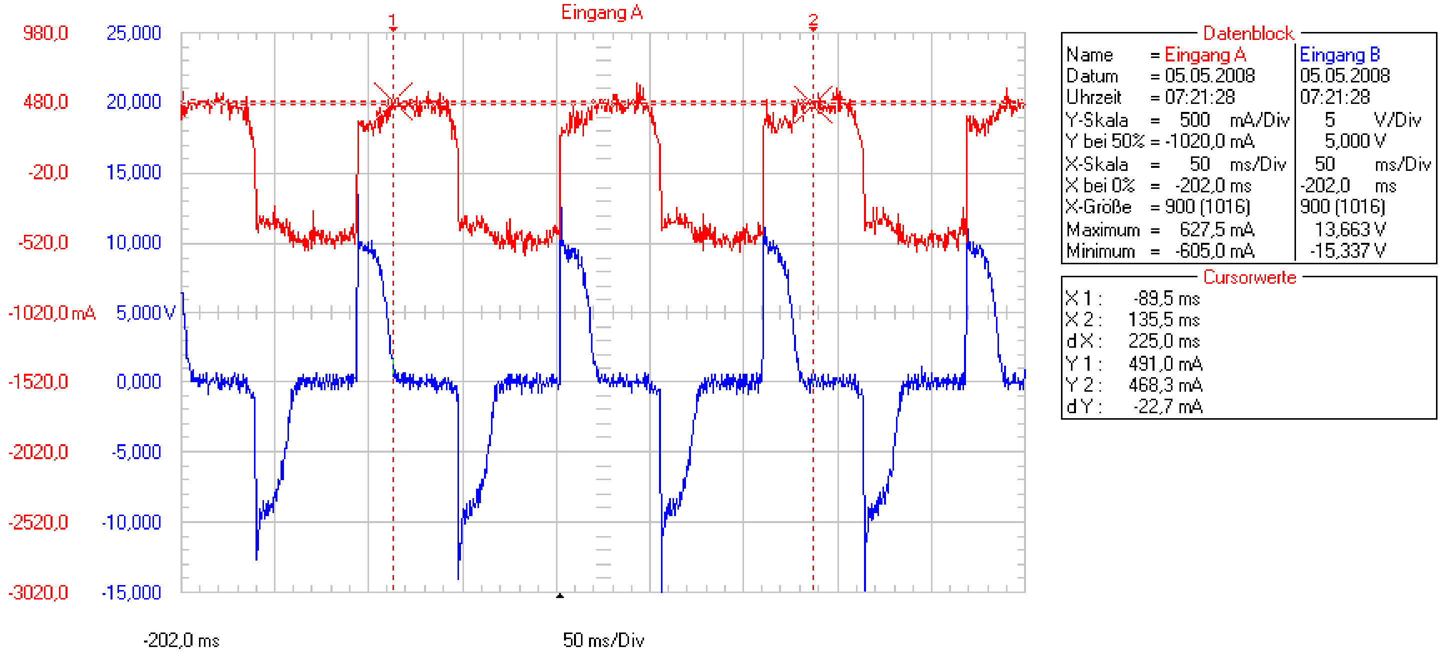


Stromwandler-test-9.bmp, wie 1 jedoch Rechteckstrom in Draht durch Wandler-Loch. mit 1k Ohm Bürde, A= Iprim, B= Usek

- The current transformer is not saturated, although the fequence is 19 Hz. The Input current is only 0,5A peak. high. The output voltage is 2,5V peak. (The effective driving voltage-time-area is 0,125Vsec. Saturation is from higher than 0,17 Vsek.)

Test on a current transformer-4.



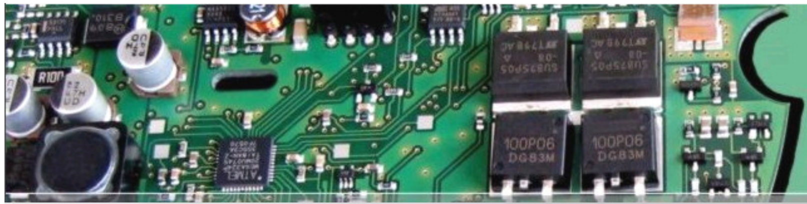


Stromwandler-test-10.bmp, wie 9 jedoch ohne Bürde. A=Iprim, B=Usek. Sättigung.

- Test like on foil before but without a load resistor. The current transformer is saturated after 20 msec. from each voltage time area. The usable voltage time area is 0,2Vsec. At higher values of it, the core goes into saturation, the blue curve breaks down.

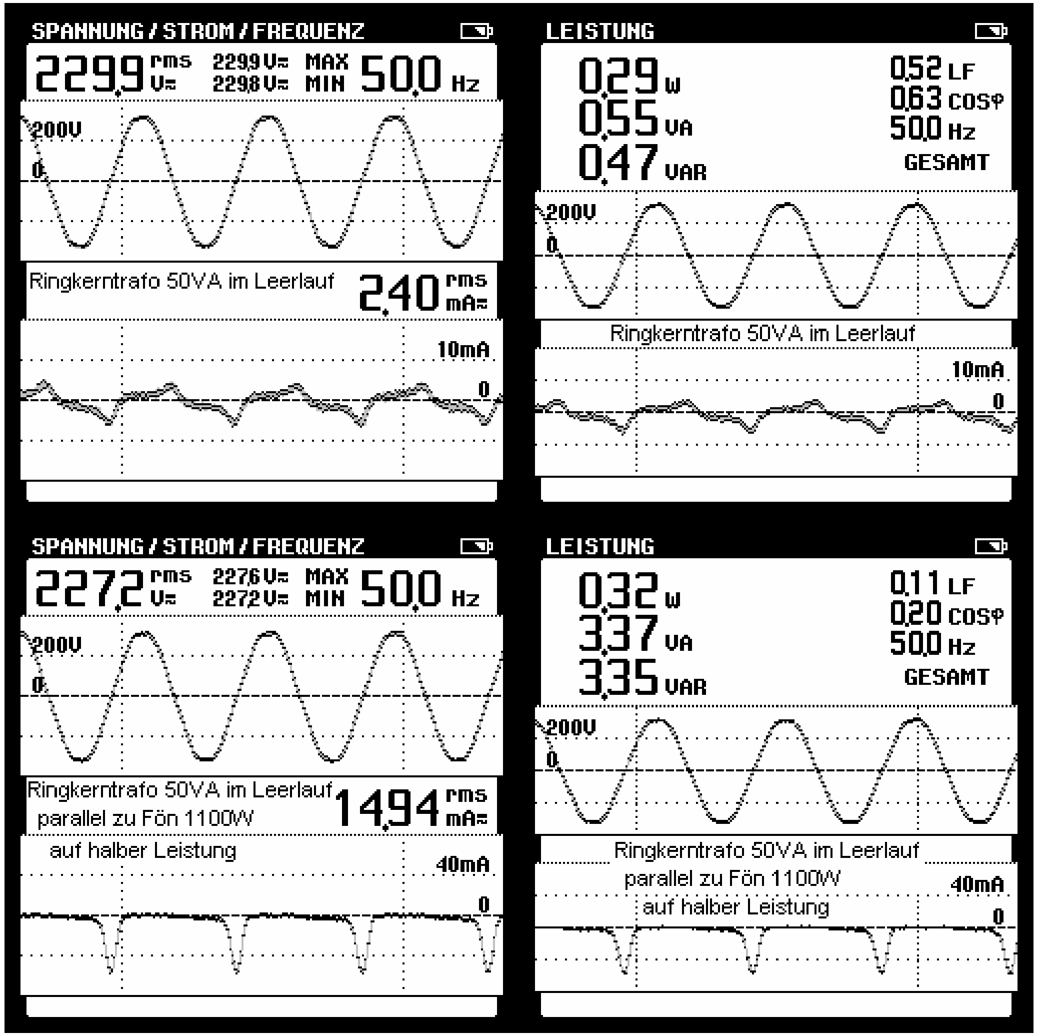
Conclusion of the current transformer tests.

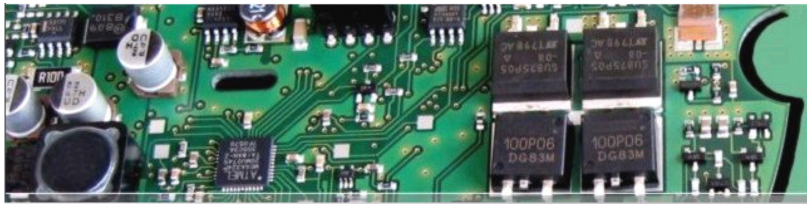
- Current transformes are constructed with a toroidal core. For that reason the current, flowing in the output coil is very low at the transport of the B on the hysteresic loop. (<<field strenght.) For that is the current signal transferred without reduction, with the effect of the voltage-time-areas on the output coil.
- This tested current transformer can transfer each shape of a current curve on his input to his output if the voltage time area on his output is not higher tan 0,2Vsec. Also at a frequence lower than 50Hz.
- Also is the evidence true, that the flow dense B in the core directly depends from the hight of the voltage time area and only indirectly from the current on his input.
- The current can not to flow out of the output if no load resistor is connected on it, and despite the signal of the output is true correspond to the input current if he is low enough. It is thanLike at an current to voltage transceiever.



Result of asymmetrically Voltagetimeareas onto a toroidal transformer.

- Measurings right are made from Deutsches Kupfer Institut, Stefan Fassbinder.
- If the negative Halfwave has a higher Amplitude than the pos. H.w., then the hysteresicloop will be not driven symmetrically. The core gets a low negative saturation at the end of each neg. Half Wave. To see at the current.
- The voltagetimearea from the neg. H.W is higher.
- In this example is a power load resistor with a rectifier in serie connected in parallel to the Transfomer at the same grid.
- The load current is not flowing through the transformer.
- Only the pos. Halfwaves are under load, why the pos. H.W. are lower than the neg. H.W. and the hystereresic loop runs asymmetrically.
- Toroidal Transformers are sensitive to dc-offest voltages, because her Core is free of an air gap.

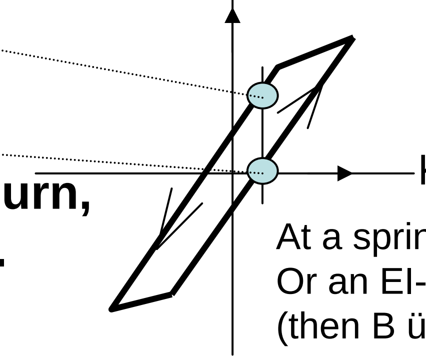




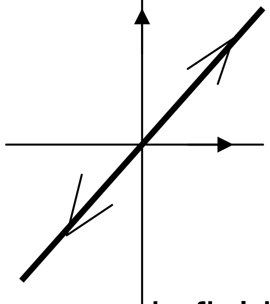
What´s an hysteresic loop?

- She shows for example at at mechanically pression spring the course of the path of the moved spring end under the influenced force.
- Or at the magnetism she shows the course of the flow dense B under the influence of the field strenght H or vice versa.
- But you can also say she describes the course of H in dependance of B and therefore from the Voltagetime area to a transformer. (B is depending of the Integral of the Voltage over the time.)

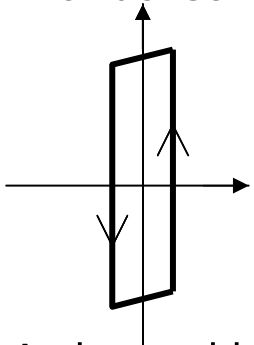
To the same force belongs backwards an other point of way than upwards.
It exists an span of retourn, the so called hysterese.



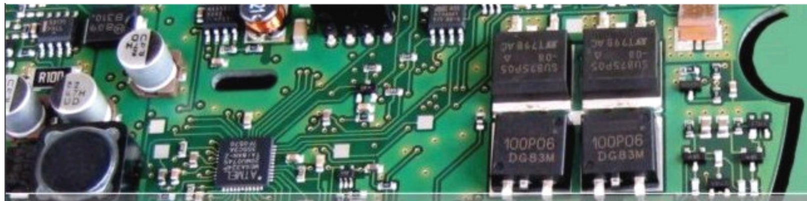
At a spring
Or an EI-core,
(then B über H)



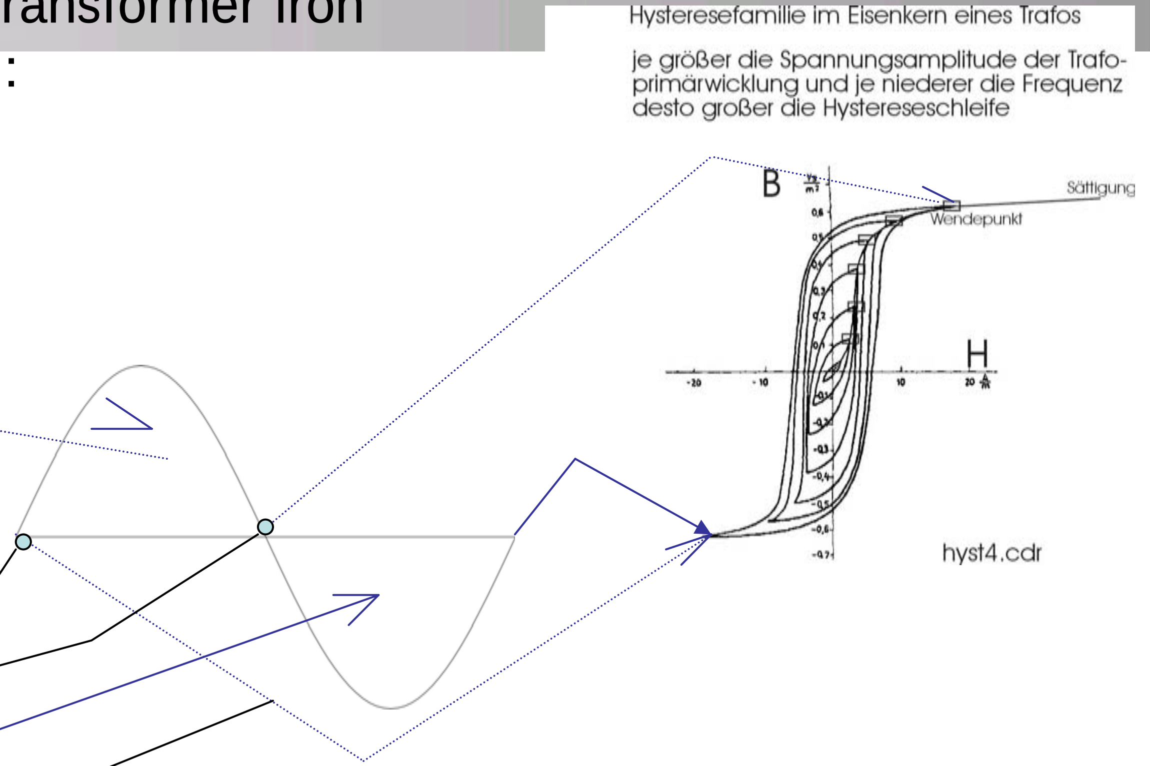
In the magnetic field
trough the air
no hysteresic loop exists.



At the toroidal Transfo
i´s a rectangular curve.



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



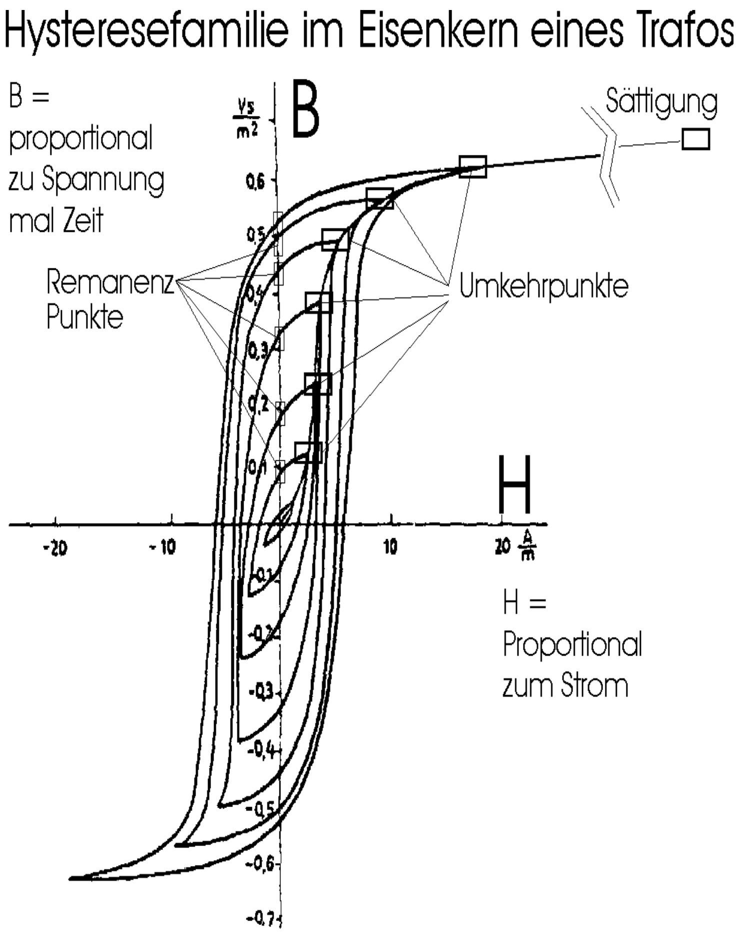
While continuous operation:

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.

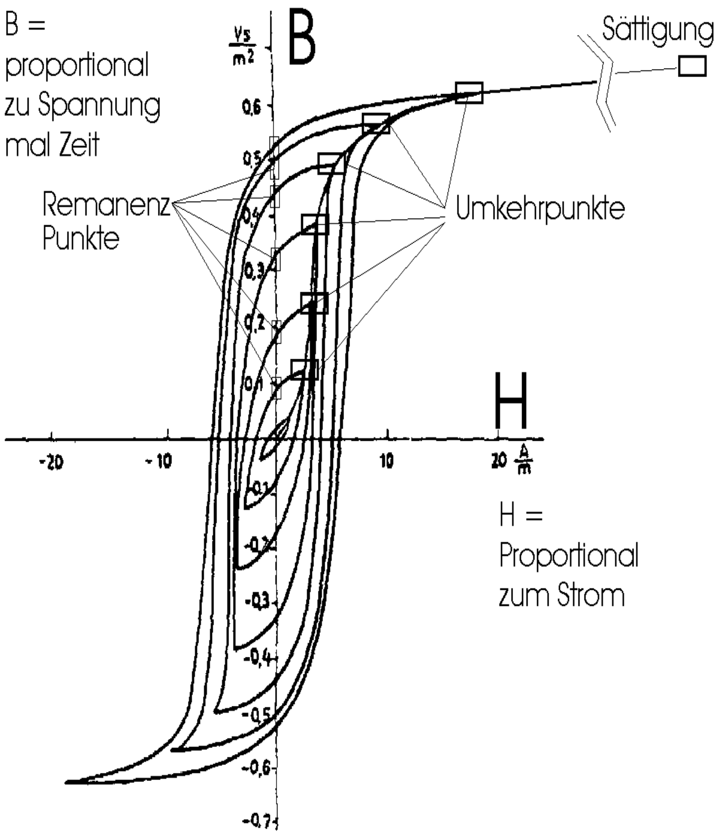
The course of B onto the Hysteresic loop is depending of the Voltage time area-1.



- 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.

Hysteresefamilie im Eisenkern eines Trafos

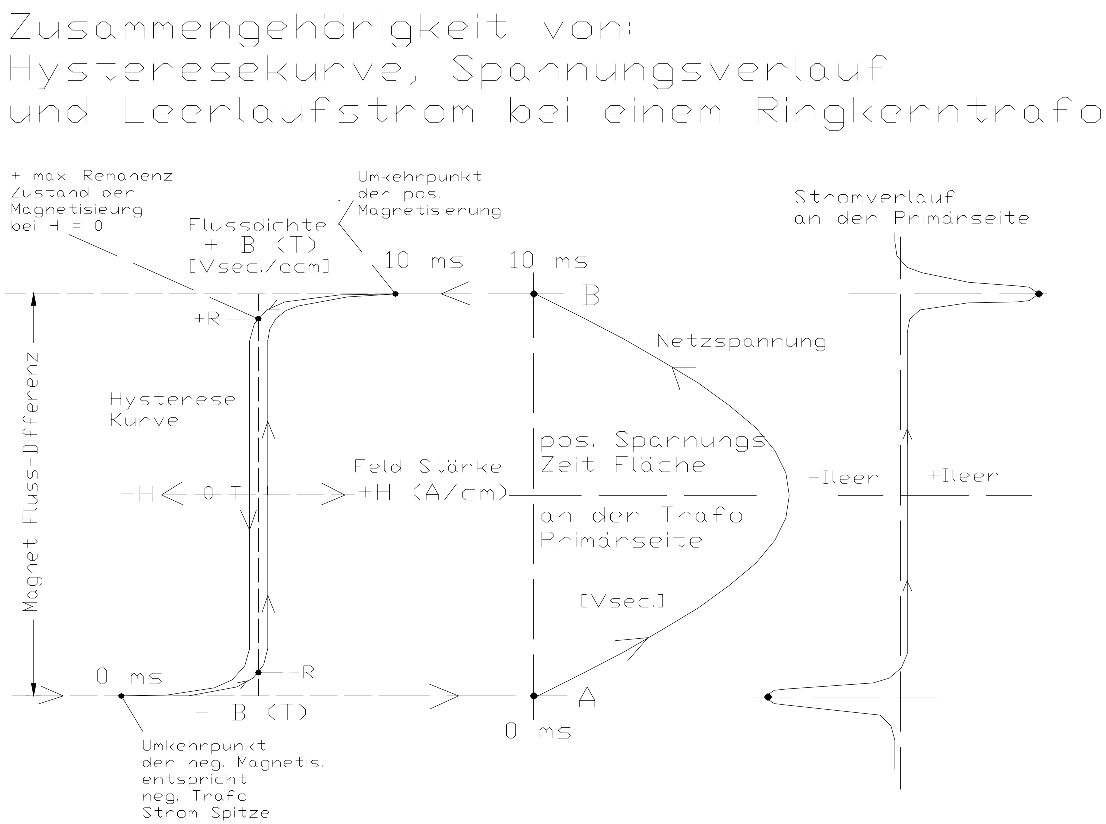


On which layer of the onion shaped curves, the B is running, is depending from the voltage and the time of periode at a given amount of windings.
A smaller time of periode, example at 60Hz, opposite to 50Hz, or a lower hight of voltage amplitude is following to a smaller, more inside laying curve.

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

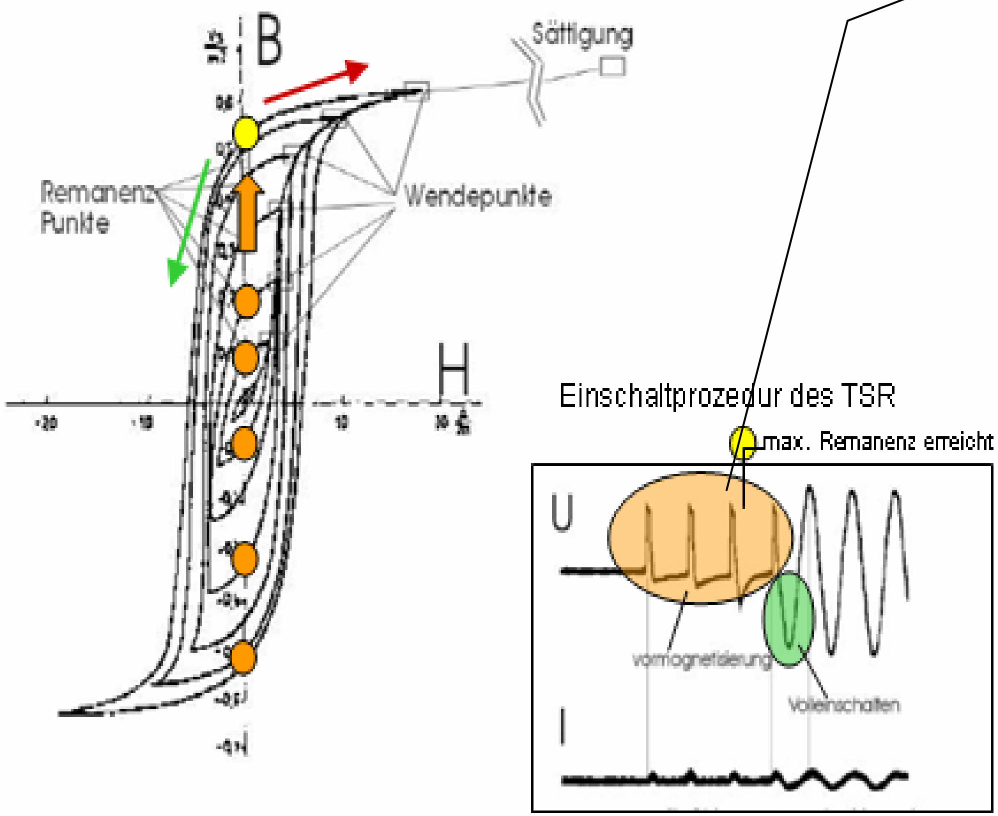
Current
I over t

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.

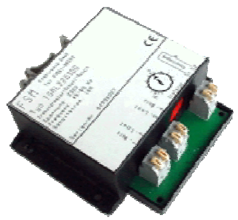
Softstart Procedure from the TSR and influence of the B.



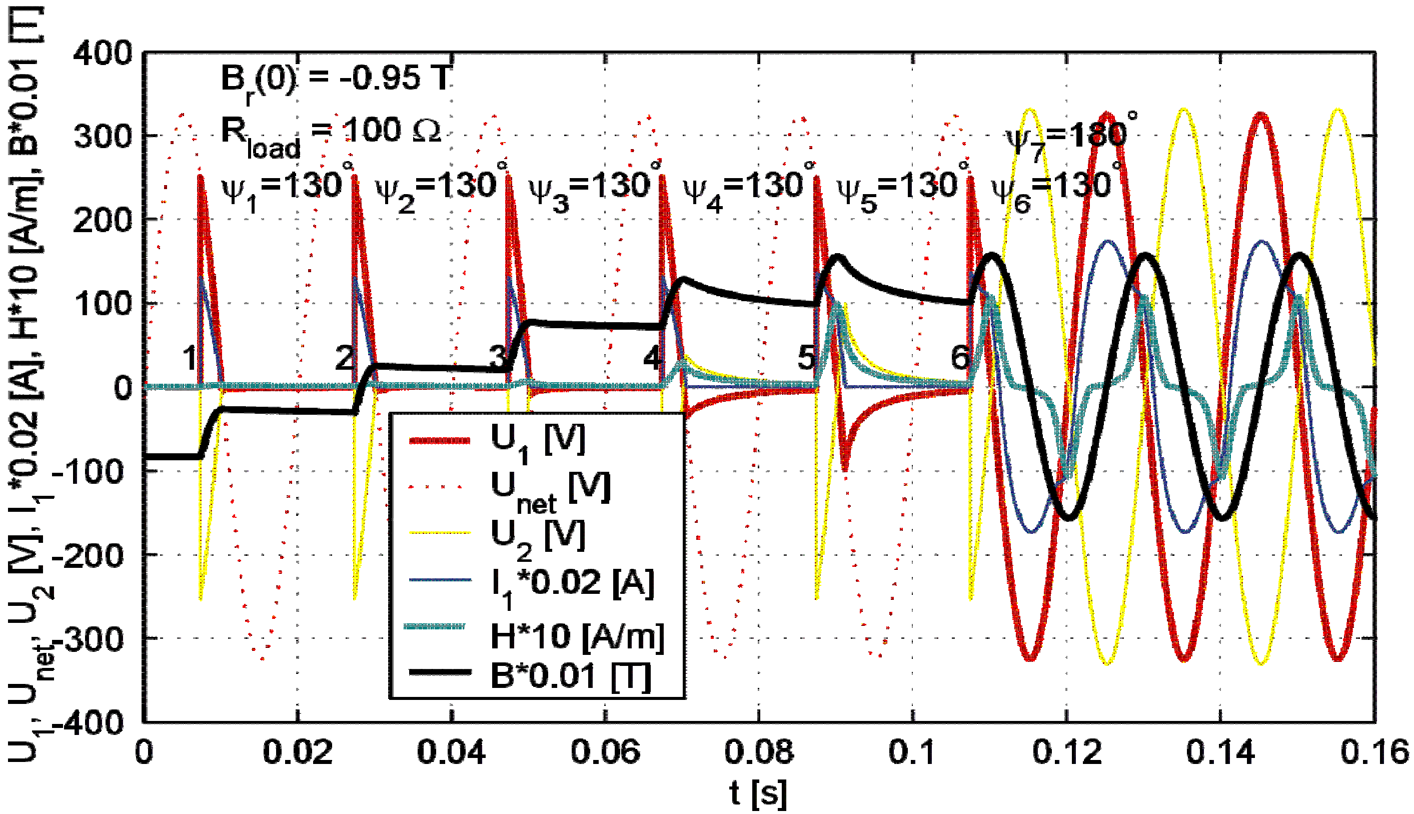
And if the B is not leaving the hysteresic loop, no inrush occurs.

Each of the positive voltagetime areas, (into the orange marked Elipse,) transports the B from the present Remnance point a piece higher to the next remnance point. (Orange marked Points on the hysteresic loop.) With a sufficient amount of voltage time areas, B reaches always the yellow marked point, the max. Remnance point.
To many voltage time areas are no problem, because each small voltage time area sending to much, transports the B from the yellow point until the belonged Return point onto the hysteresic loop. In the pause the B runs back to the max. Remnance, the yellow marked point. At the following full switch on, (green marked Ellipse,) starting in zerocrosspoint, the B runs like in continuos running mode onto the hysteresic loop.

Transformer soft-start with an EI Core. Start at B = -0.95 Tesla, Max. Remnance Point at + 1 Tesla



Elektronik GmbH
Kirchzarten



B runs onto the black curve. The Transfo is under load, sinusoidal shaped current from. 3,6Apeak. No inrush to seen

To understanding of the things happen inside of the transformer core, it is important to understand,

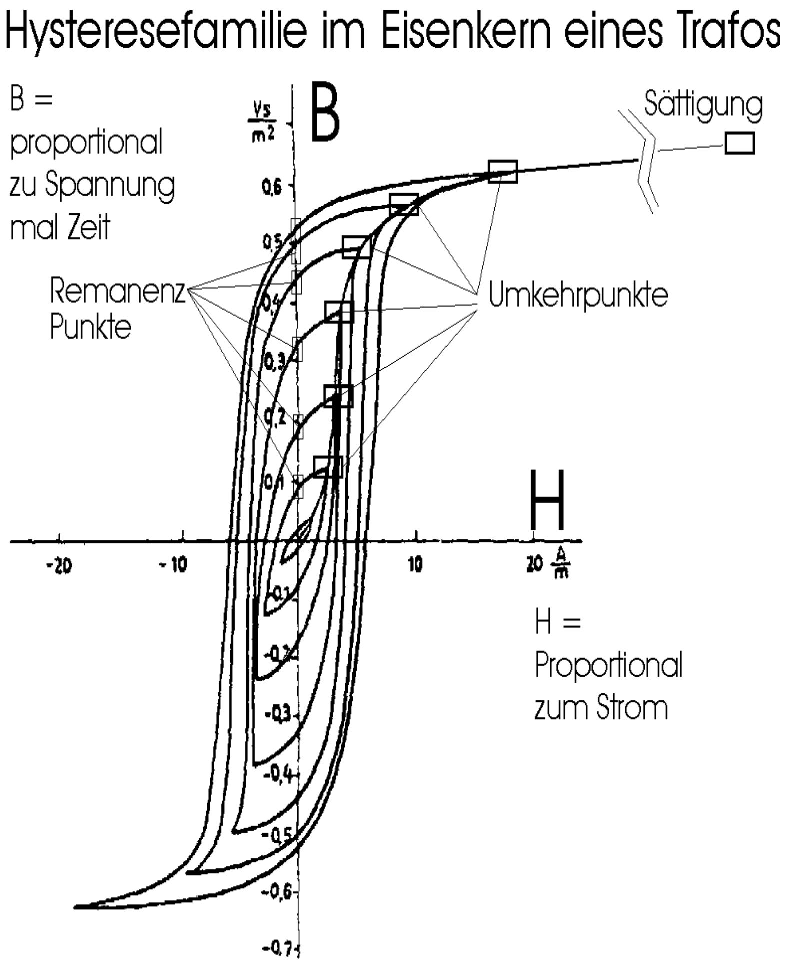
a.) That the unipolar voltage time areas only inside the linearly course of the hysteresic loop are to be integrated until the max. Remnance point.

b.) That these Integration and for that the Transport of the B in one direction stops, if the hysteresic loop is leaving in direction to a low saturation.

c.) Dont care 0f the magnetisation of the core, also brought into saturation, only the max. Remnance can be reached in idle state, if the voltage time area is over.

d.) The iron core can only be brought until the max. Remnance point not higher to be resting in the idle state.

Hysteresic loop and Function of TSR.

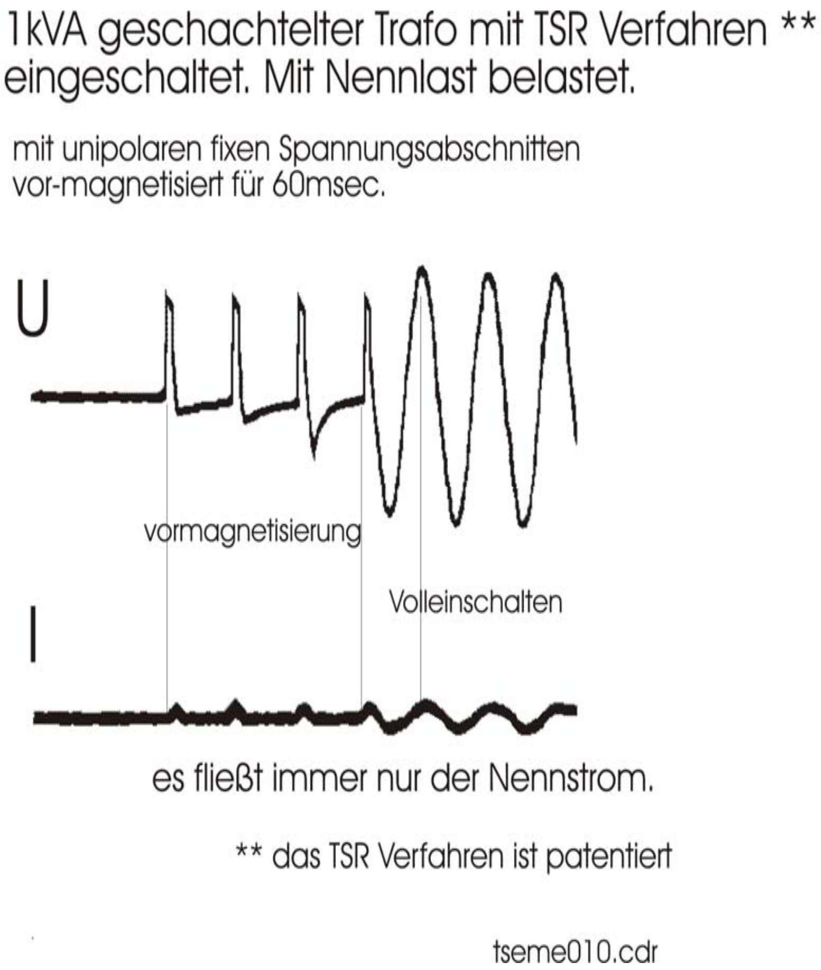


- After each voltage time area the magnetisation reaches an higher point as bevore.
- Before the end of the premagnetisation procedure the B max. point is reached, and to the end of the last voltage time area the transformer will be switched full on.
- To many voltage time areas are no problem.

- The Saturation is avoided in all circumstances.
- The width of the voltage time areas must to be adjusted to the shape of the hystereseic loop.
- (The adjusting value depends of the vertically distance from the max. Remnance point to the turning point on the hysteresic loop.)
- The load or no load state has no influence of the adjusted value.

- For that a trimmer is placed onto the board of the TSR.

Voltage and Current- measuring curves from the TSR softstart procedure.



- To full switch on, the Thyristor, producing the premagnetising impulses, gets to be shorted from an electro mechanically relays.
- The relays helps the Thyristor and the Thyristor helps the relays. The relays protect him from overheating and for overcurrent peaks. And the Thyristor protects the relays contact from the lightning spark.
- For that a life time of more than 5 Millions switching cycles under nominal load are reached.
- The relay alone can only switch such a load for 25.000 times until weared out.
- At switch on only the resistive current from the load resistor is to seen, no inrush current peak occurs.

Developed at the Fraunhofer Gesellschaft.

- The inventor of the TSR –units:
- Emeko Ingenieur Büro, Michael Konstanzer in Freiburg.
- Here a photography from 1994 for the journal Fraunhofer, for the Award from Fraunhofer for him.
- From 1996 until 2006 M.Konstanzer was working at Fraunhofer in parttime.
- After that he works at a freelancer for the marketing and customer consulting for the TSR Applications.

Manufactor of all TSR

The manufactor and further developer of the TSR –since 1998:

Fsm-Elektronik. In Kirchzarten at Freiburg.

In 2011 with 90 employes.

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