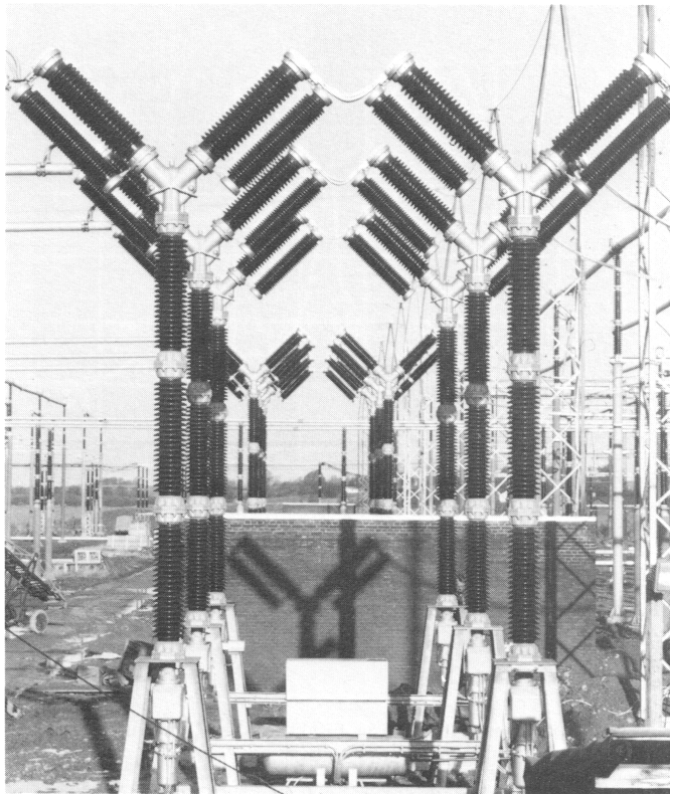
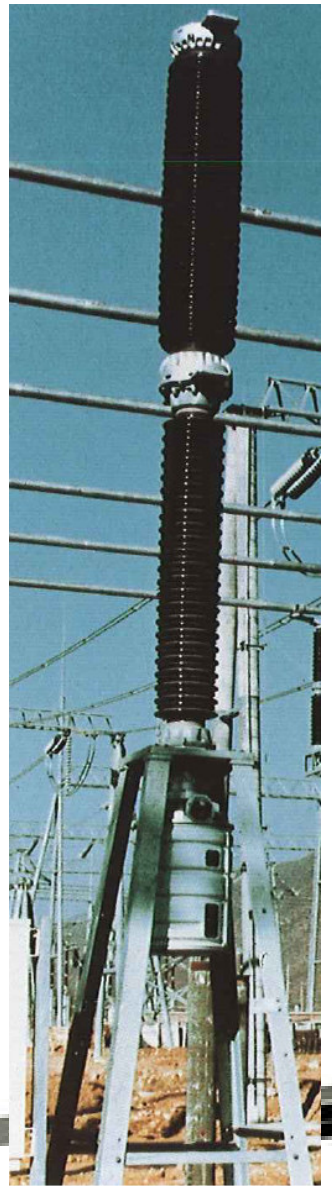
Evolution of SF6 breaker

Compared with
Measurement techniques
Development techniques
and development of
Standards





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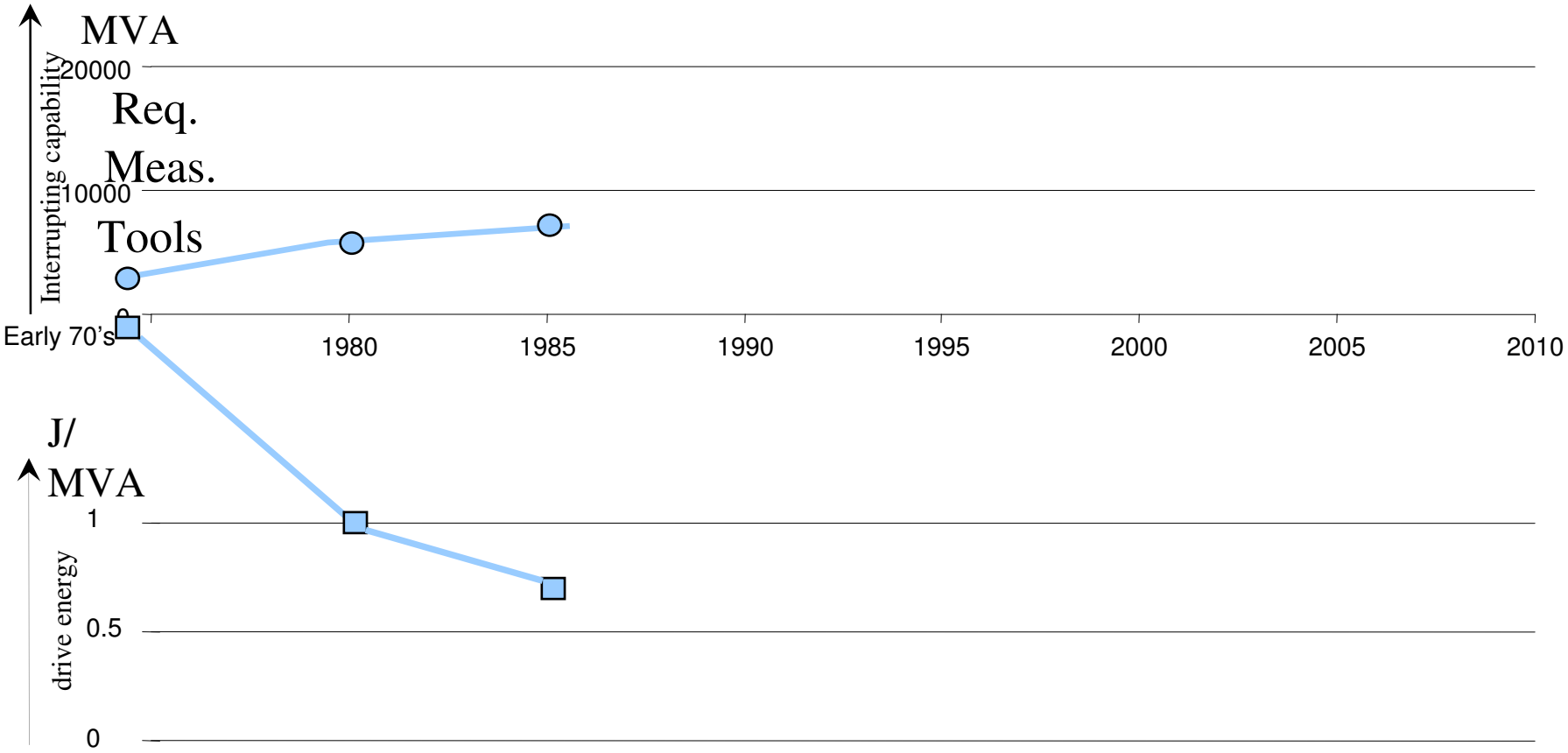
Overview SF_6-Circuit Breakers



1nd Generation: **Puffer Breaker**

- Extinguishing pressure generated during current breaking → high demand on drive energy
- How? Cylinder-Piston-Compression
- Current breaking: arc extinguishing

IEC standard mid 70‘s

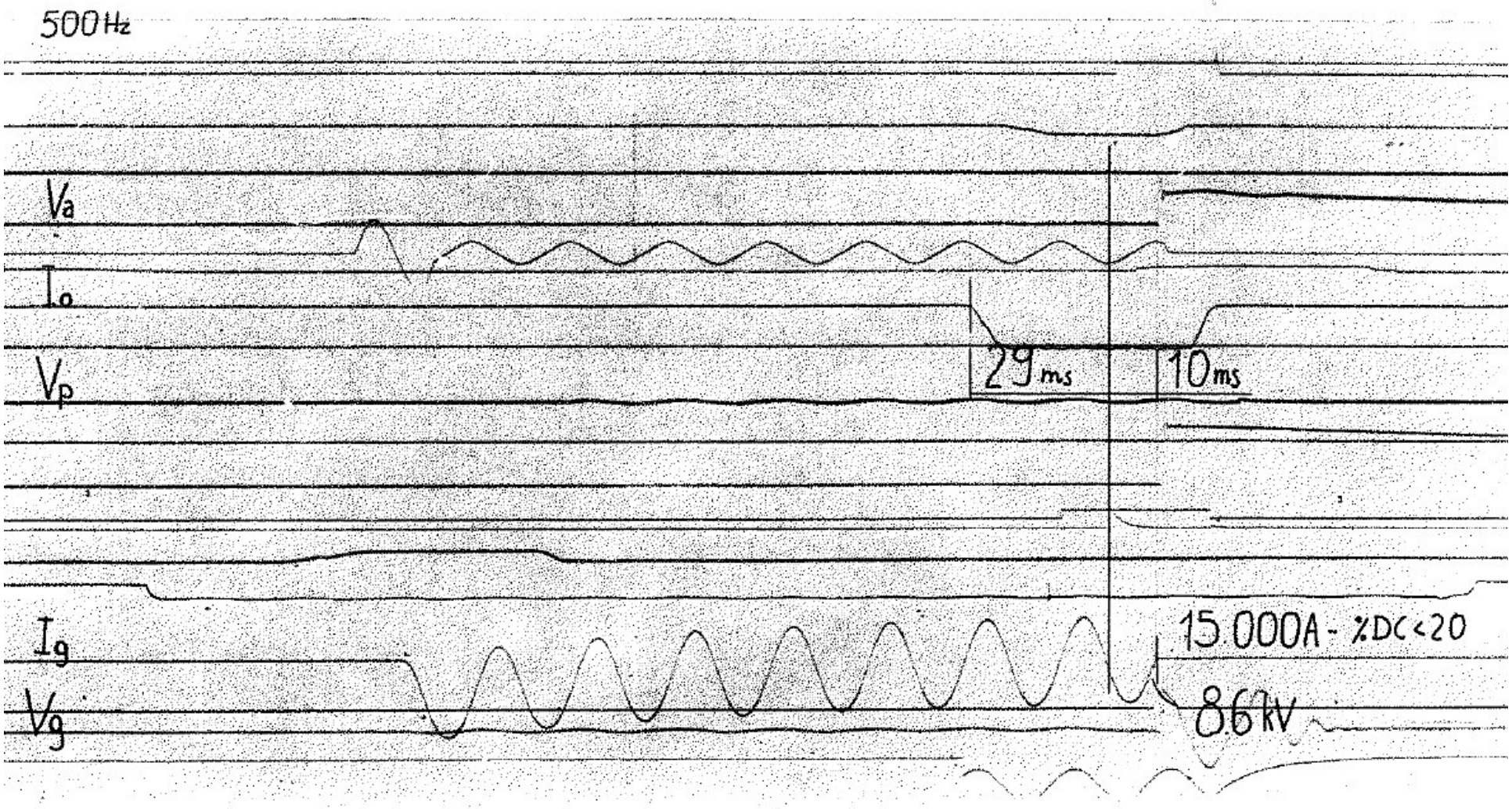
- Du/dt terminal fault
  - 100% fault 1 kV/us
  - 60% fault 2 kV/us
  - 30% fault 5 kV/us

- Short line fault newly introduced
  - Different line side impedances
    - 480 Ohm single conductor
    - 375 Ohm double conductor
    - 330 Ohm 4 conductors
  - Source side rate of rise 0.67 kV/us
  - Time delay line side ????
- Cap switching tests prescribed
- Mechanical endurance 1000 operations

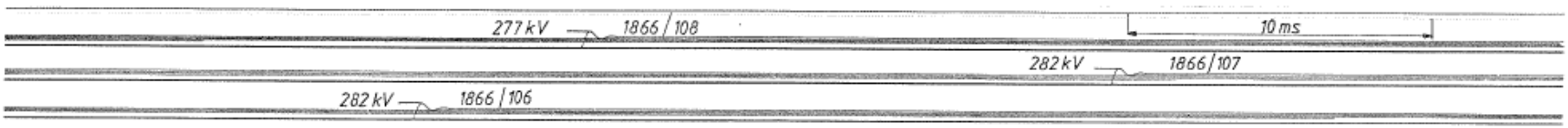
Measurements type tests 70‘s

- Low speed
  - **UV sensitive paper**
  - Ink/pencil
- Medium speed
  - „schleifen(Drum) oscillogram“
- High speed
  - Storage oscillograph
  - Peak volt meter

Overview Oscillogram 1



Schleifen(Drum) oscillograms



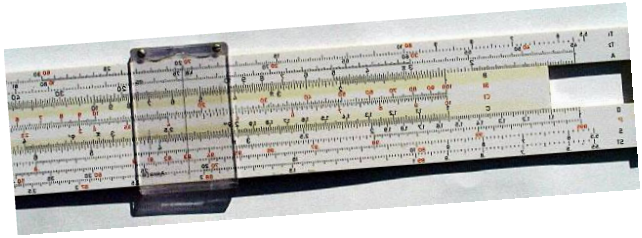
- Used for medium time scales (TRV peak and up to e few 100ms)
- Needed to be developed (like a picture)
- Available approx 5 min after the test
- Evaluation by hand (pencil)
- Max deflection approx. 20mm
- In order to save time often more than one test have been recorded on one oscillogram
- The lenght of such an oscillogram was in the order of 1 m

Measurements development tests 70‘s

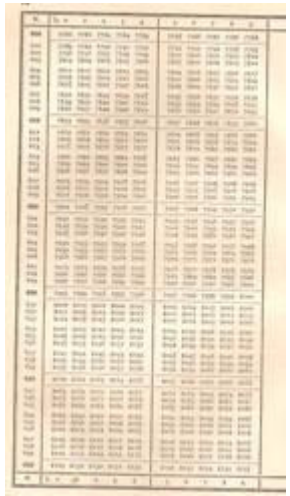
- Voltage
  - applied
  - Arcvoltage
  - TRV
- Current
- Travel
- Partly pressure

Calculation/simulation tools 70‘s

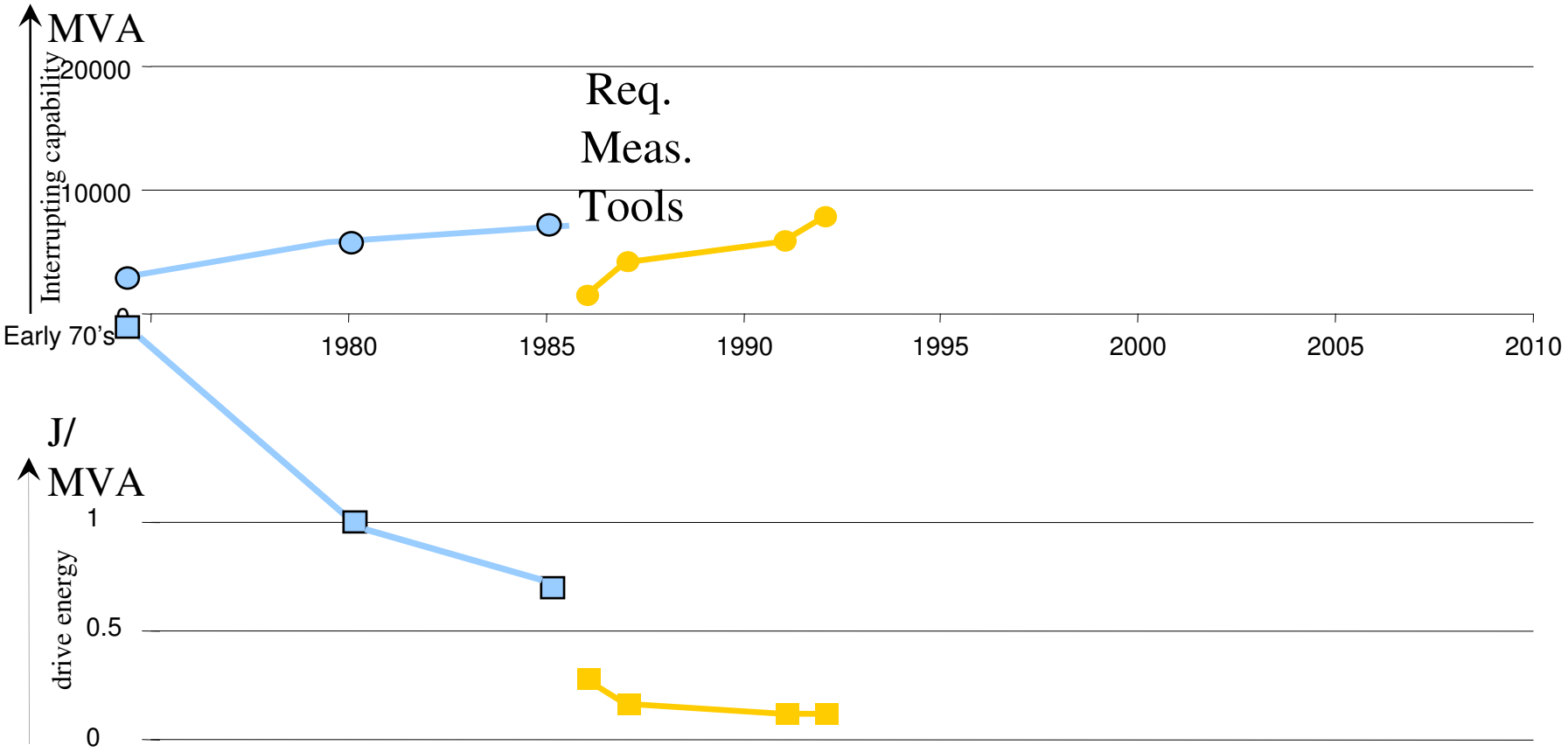
- Cold static Dielectric
  - Experience
  - Basic knowledge



- Pressure build up
  - Analytic formulas(basic physics)
  - First simulations using mainframes or first programmable desktops
- Flow
  - assumptions
- Drive
  - Analytic formulas
- Mechanical withstand capability
  - Tables for slow/long term behaviour/experience



Overview SF_6-Circuit Breakers



2th Generation: Self Blast Breaker

- Extinguishing pressure mainly generated from arc energy
- Cylinder-piston compression only for lower currents
- Significant reduction of needed drive energy

IEC standard mid 80‘s

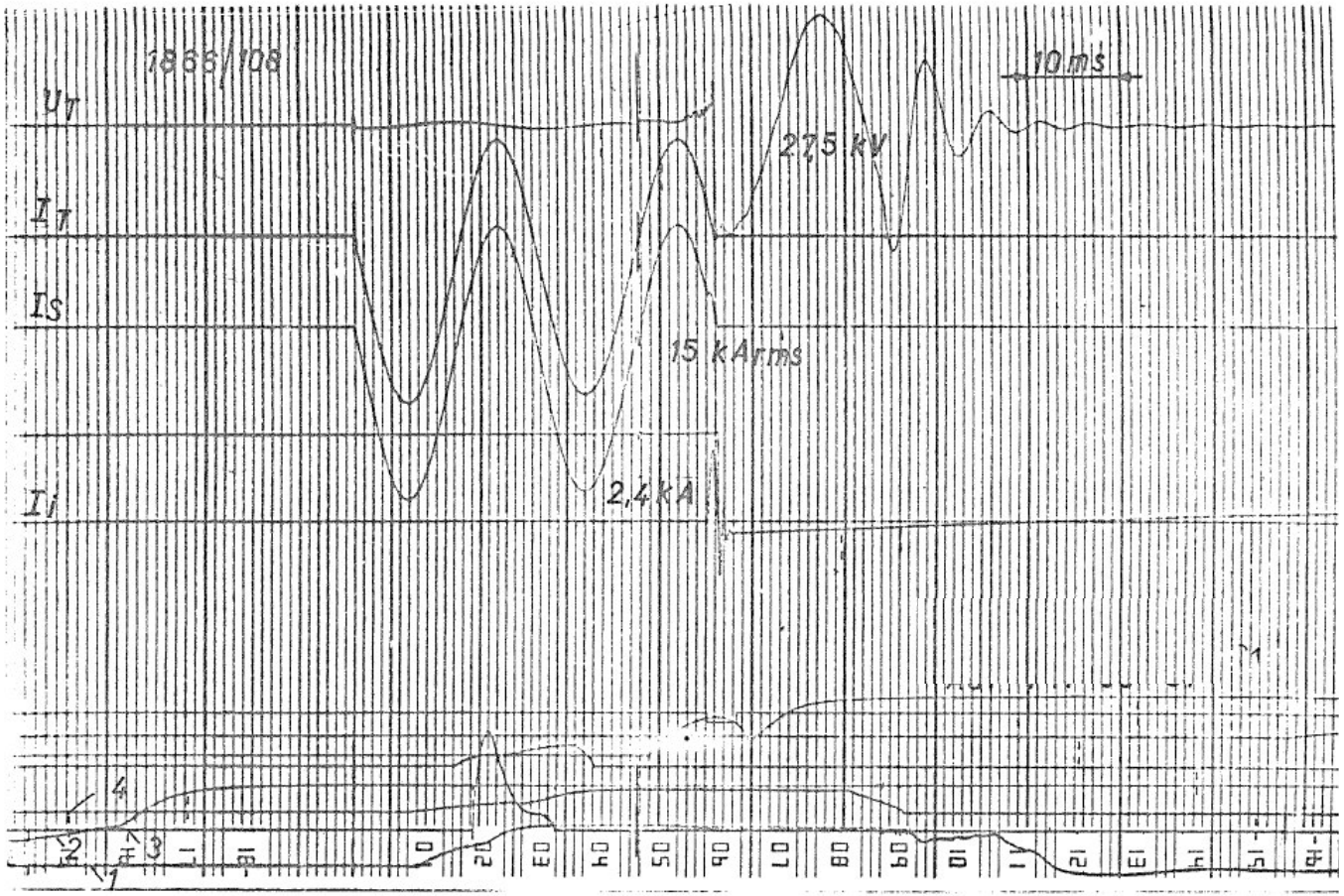
- Du/dt terminal fault
  - 100% fault 2 kV/us
  - 60% fault 3 kV/us
  - 30% fault 5 kV/us

- Short line fault
  - single line side impedance 450Ohm
  - Source side rate of rise 2 kV/us
  - Time delay line side 0.2, 0.5 us
- ITRV switching condition
- Cap switching tests splitted in
  - 4 testduties with 12 tests each
  - Defined first phase factors (1.2, 1.4, 1.7)
- Mechanical endurance 2000 operations

Measurements type tests 80‘s

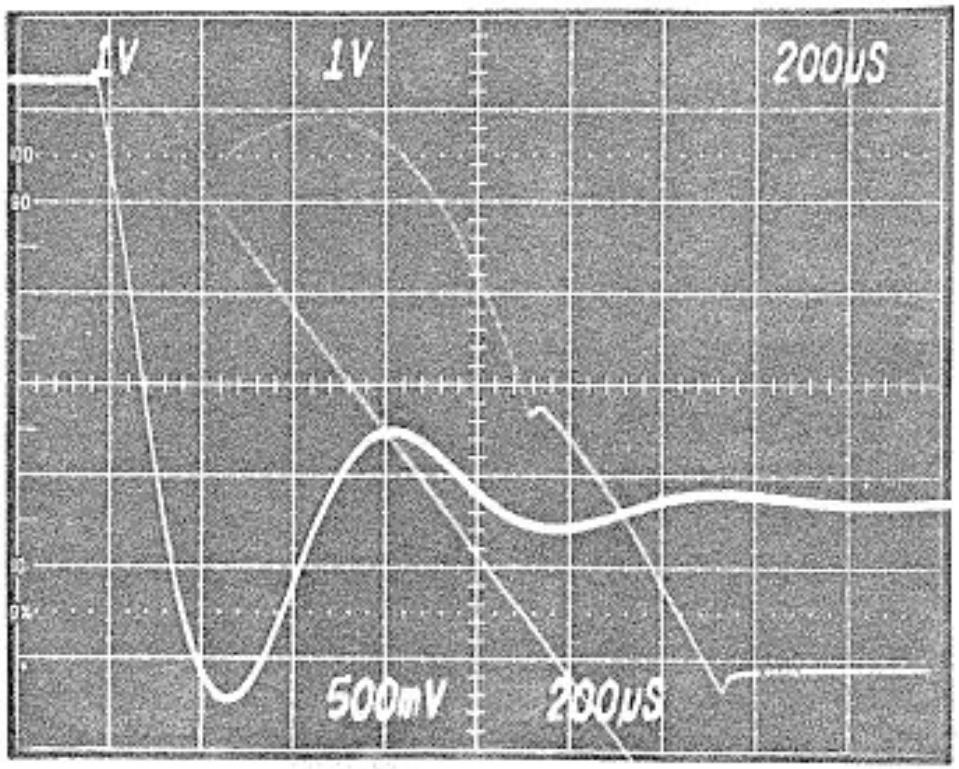
- Low speed
  - UV sensitive paper
  - First digital Transient recorders/measurement systems
- Medium speed
  - „schleifen oscillogram“
  - First digital Transient recorders
- High speed
  - Storage oscillograph
  - Oscillograph with polaroid pictures
  - First digital Transient recorders

UV oscillograms



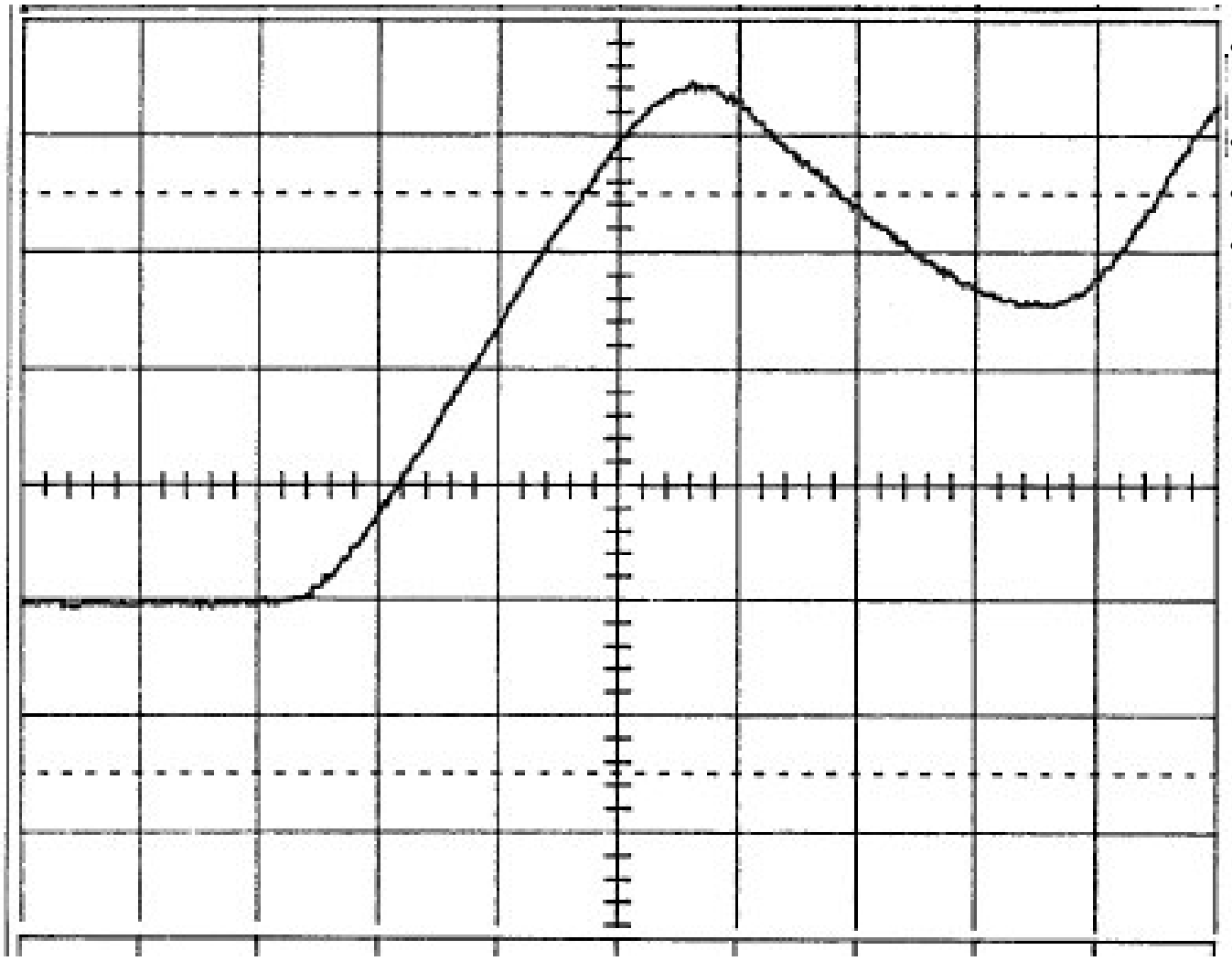
- Available a few min after tests
- Evaluation by pencil
- Approx 20 traces possible
- Max deflection approx 30mm

Polaroid Pictures



- Used for fast transients
- TRV peak
- Line side peak (SLF)
- Current zero region
- Evaluation by pencil
- Needed to be developed (by itself)
- Oscillograph needed exact triggering
  - Otherwise information lost

First digital transient recordes



- Used in the same way as the polaroid pictures
- Only few channels
- Not so much points
- Time resolution ok for short line fault TRV‘s

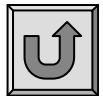
Measurements development tests 80‘s

- Voltage
  - applied
  - Arcvoltage
  - TRV
  - PD
- Current
- Travel on different locations (may be on potential)
- Pressure in different volumes (may be on potential

Calculation/simulation tools 80‘s

- Cold static Dielectric
  - 2D Finite element programs running on a mainframe
    - To be programmed by specialists
- Pressure build up
  - Integral simulation programms running on workstations
  - Later on transfered to PC‘s
- Flow
  - 2D Finite element calculation programs running on a mainframe
  - To be programmed and interpreted by specialists
  - Needed CPU time several days
- Drive
  - Integral simulation programms running on workstations
- Mechanical withstand capability
  - 2D Finite element programs running on a workstation

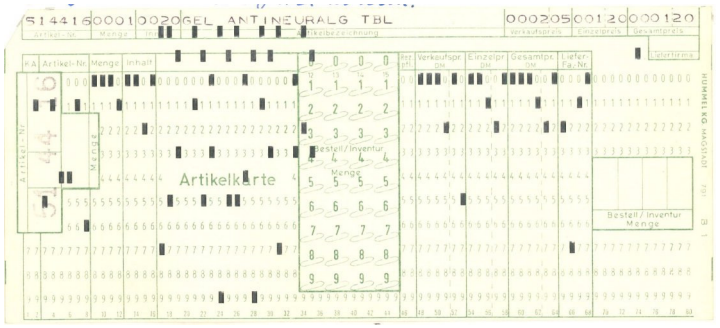
- **Mostly stand alone programs**



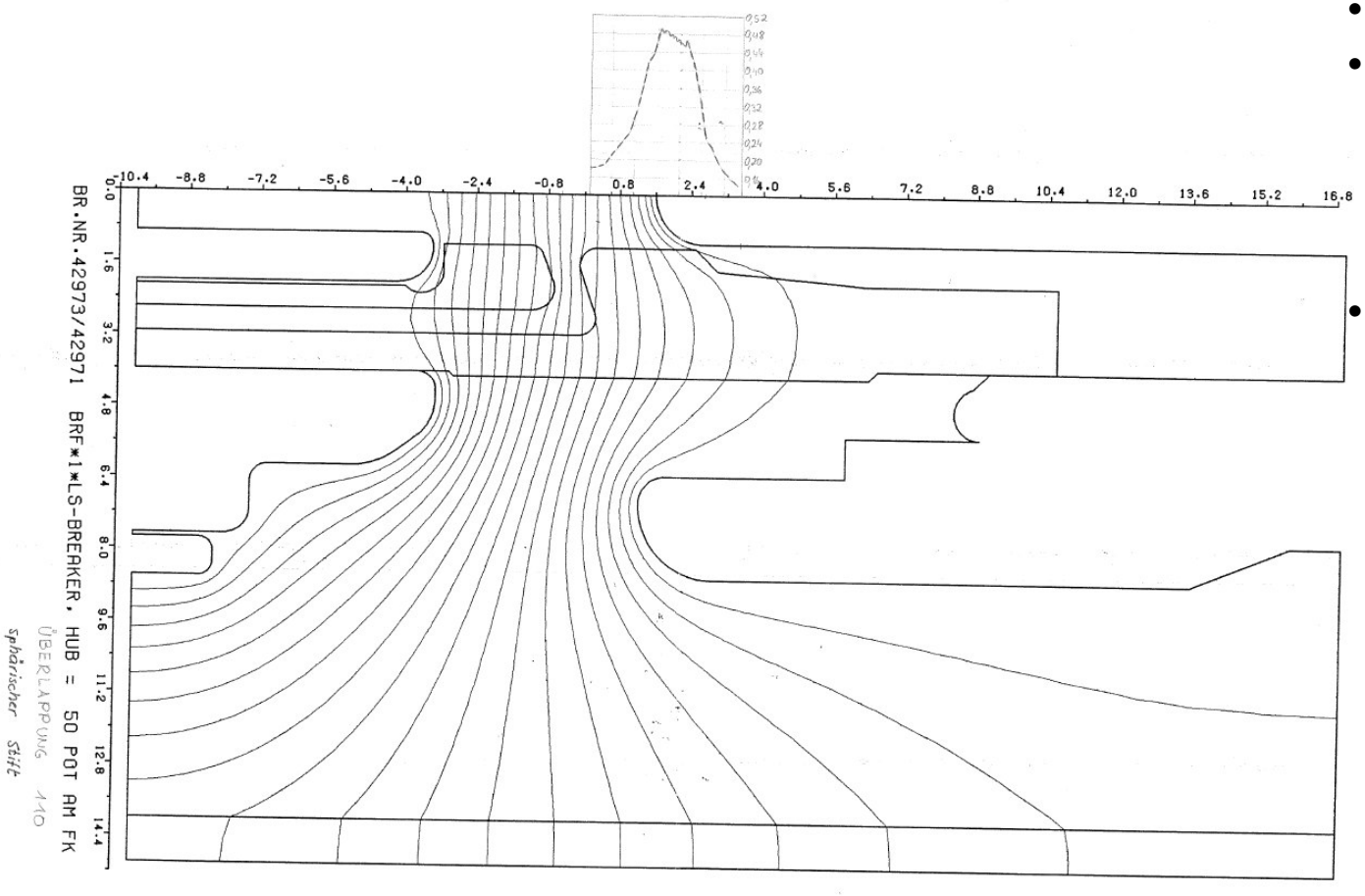
Fieldcalculation Mainframe input

```
C  ****************************
C  **DEFINITION DER FIGUREN**
C  ****************************
C 28 *FESTKONTAKTTRAEGER KPL
     FIGURDEF 28
     / -1 23.7 / 6.30 23.7 / 6.30  4.40 / 6.6948  3.8362 KREIS 6
     SEGMENTW 4 / 7.5156  3.8362 KREIS 6
     SEGMENTW 4 / 8.57  4.5 / 8.57 16.65 KREIS 11 SEGMENTW 4
     / 7.7 18.85 KREIS 10 0.5 / 7.7 20.8 KREIS 5 0.2 90 / 7.5 21.0
     / 7.5 107.0 / 16.8 107 / 16.8 100 KREIS 5 0.5 90 KREIS 5 4 90
     / 21.3 109 KREIS 5 3 90 / -1 112
C 25 *ANTRIEBSKONTAKTTRAEGER INCL. FLANSCH MITTELARMATUR
     FIGURDEF 25
     / -1 -20.65 / 5.5 -20.65 / 5.5 -109.1 / 16.8 -109.1 / 16.8 -100.1
     KREIS 5 -.5 90 KREIS 5 -4 90 SEGMENTW 5 / 21.3 -118.6 KREIS 5 -4
     90 SEGMENTW 5 / 13.0 -122.6 KREIS 5 -0.5 90 / 12.5 -115.1
     / -1 -115.1
C 01 *FESTKONTAKTSTIFT
     FIGURDEF 01
     / -1 9.75 / 0 9.75 KREIS 5 1.1 90 SEGMENTW 5 / 1.1 36.5
C 10 *ABBRANDFINGER
     FIGURDEF 10
     / 2.1  -9.300 / 2.1  -4.15  /  1.22   -3.4009 KREIS 6 SEGMENTW 4
     /                                1.0   -3.4 / 1.0 -9.3
     KREIS 11 SEGMENTW 4
C    / 2.7 -9.25 / 2.7  0.0866 / 2.075 -3.494 KREIS 6 SEGMENTW 4
C    / 1.4856 -3.442 KREIS 6          SEGMENTW 4 / .95 -3.2 / .95 -9.3
C    KREIS 11 SEGMENTW 4
C 11 *HILFSDUESE
     FIGURDEF 11
     / 2.70 -9.25  / 2.70  0.0866 / 1.95  0.5196 KREIS 6 SEGMENTW 4
     / 1.40  0.202 / 1.20 -0.231  KREIS 6 SEGMENTW 4 / 1.20 -3.0   /
      1.8 -3.0   KREIS 10 0.1 SEGMENTW 4 / 2.3 -3.59 KREIS 6 SEGMENTW 4
     / 2.3  -9.25
C 12 *ISOLIERDUESE
     FIGURDEF 12
     / 4.0 -6.50 / 4.0 -5.3 / 3.9 -5.1 KREIS 10 .1 / 3.9 10.9
     KREIS 10 0.1 KREIS 5 0.2 90 / 2.8 11.1 / 2.00 8.3 KREIS 10 0.2
     / 2.00 6.5402 / 1.866 6.0402 KREIS 6 SEGMENTW 4 / 1.30 4.8
     / 1.30  1.60 / 1.821 1.1302 KREIS 6 SEGMENTW 4 / 2.629 1.424
     / 3.3 0.954    KREIS 6 SEGMENTW 4 / 3.3  -10.5
C 13 *KONTAKTRING
     FIGURDEF 13
     / -1 -8.30 / 4.0 -8.3 / 4.0 -5.3 / 4.10 -5.15 KREIS 10 0.1
     / 4.10 -4.7 KREIS 10 0.1 / 4.3237 -4.3805 KREIS 6 SEGMENTW 4
     / 5.0972 -4.3128 KREIS 6 SEGMENTW 4 / 5.7039 -4.6993 KREIS 6
     SEGMENTW 4 / 5.97 -5.21   KREIS 6  SEGMENTW 4 / 6.1 -5.2
```

- Definition of contuors by means of coordinates and transitions
- At early times it was necessary to define the complete input on punchcards
- Later it was possible to define it in special input files on remote terminals

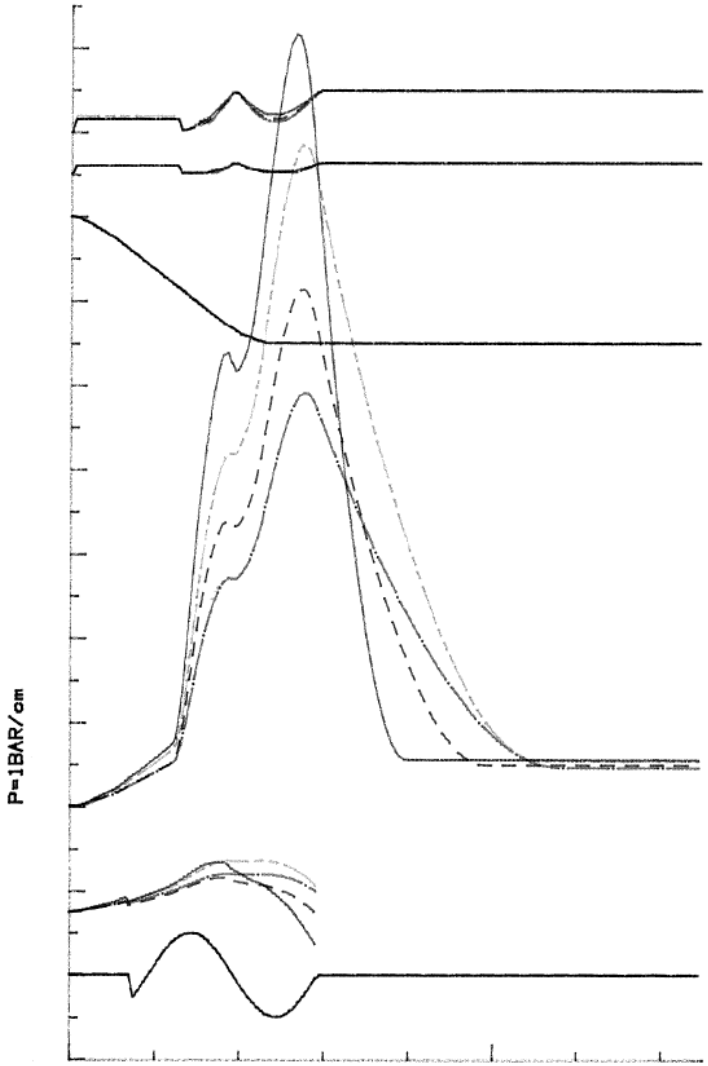


Fieldcalculation Mainframe



- CPU time up to hours
- Since the calculation was running on a mainframe it was necessary to que
- Time needed for one run was approx 1 day
  - If the shape was existing
  - Starting from scratch was approx 1 week

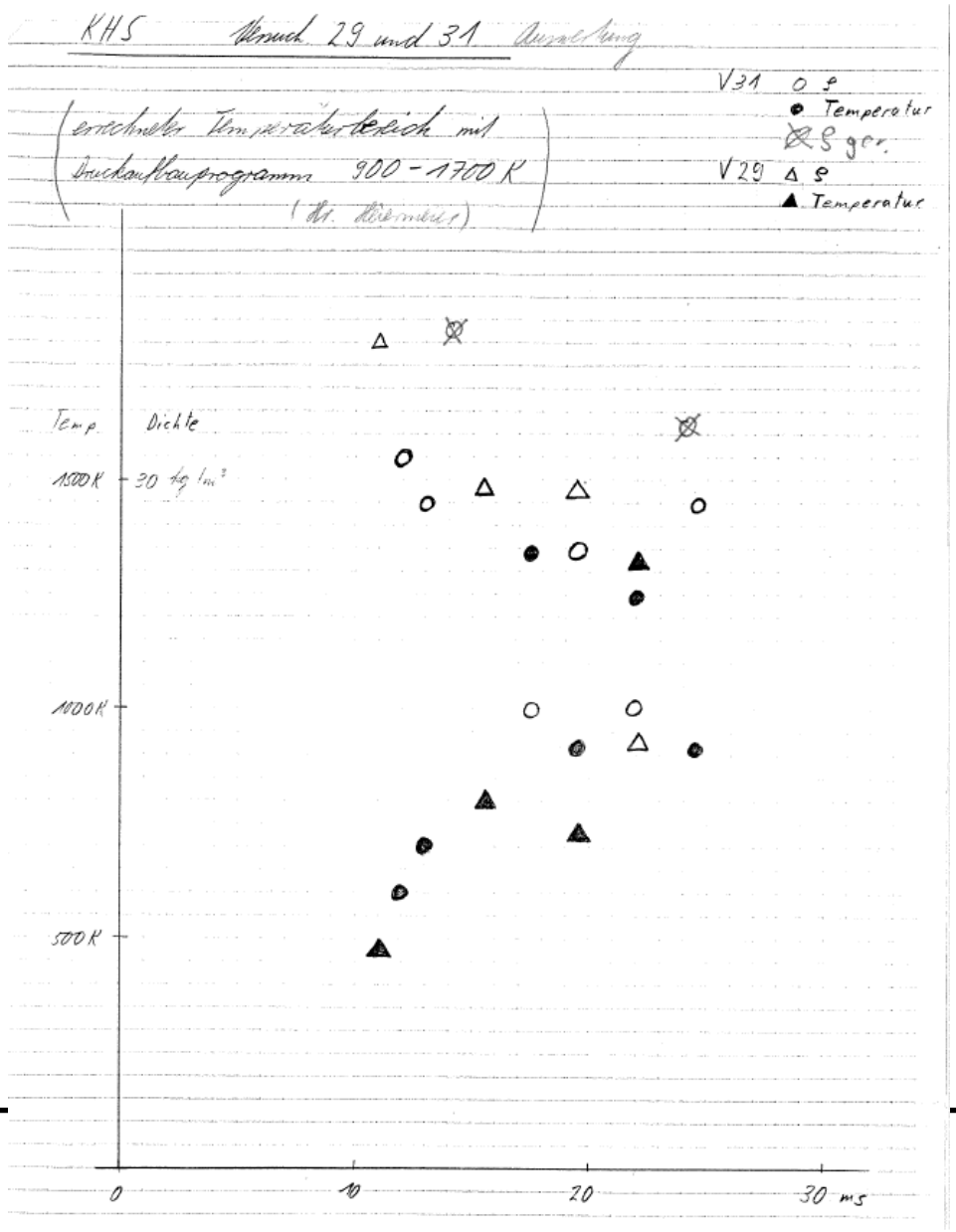
Pressure calculation program 1. gen




```
          DI9.PLT
Ieff[kA] 25.00  TLB[ms]  22.0 ASY[%] 0.00
PMAX[BAR] 24.3 EKOM[J] 154.8 ETA1[%]25.0
PLOE[BAR] 21.2 XVER[]   0.7
   VSG2 65 CM**2 .4L          1327°K
DICHTE IM LOESCHM (GR/L) 27.10
          DI10.PLT
Ieff[kA] 25.00  TLB[ms]  22.0 ASY[%] 0.00
PMAX[BAR] 18.3 EKOM[J] 100.4 ETA1[%]25.0
PLOE[BAR] 17.5 XVER[]   0.7
   KHS SB11 65KO .7L          936°K
DICHTE IM LOESCHM (GR/L) 34.92
          DI11.PLT
Ieff[kA] 25.00  TLB[ms]  22.0 ASY[%] 0.00
PMAX[BAR] 15.8 EKOM[J] 107.4 ETA1[%]25.0
PLOE[BAR] 15.4 XVER[]   0.7
   KHS SB10 1L TOTVOL         670K
DICHTE IM LOESCHM (GR/L) 39.70
          DI12.PLT
Ieff[kA] 25.00  TLB[ms]  22.0 ASY[%] 0.00
PMAX[BAR] 21.7 EKOM[J] 159.2 ETA1[%]25.0
PLOE[BAR] 20.9 XVER[]   0.7
   KHS SB12 .7LTOTV.          868°K
DICHTE IM LOESCHM (GR/L) 41.35
```

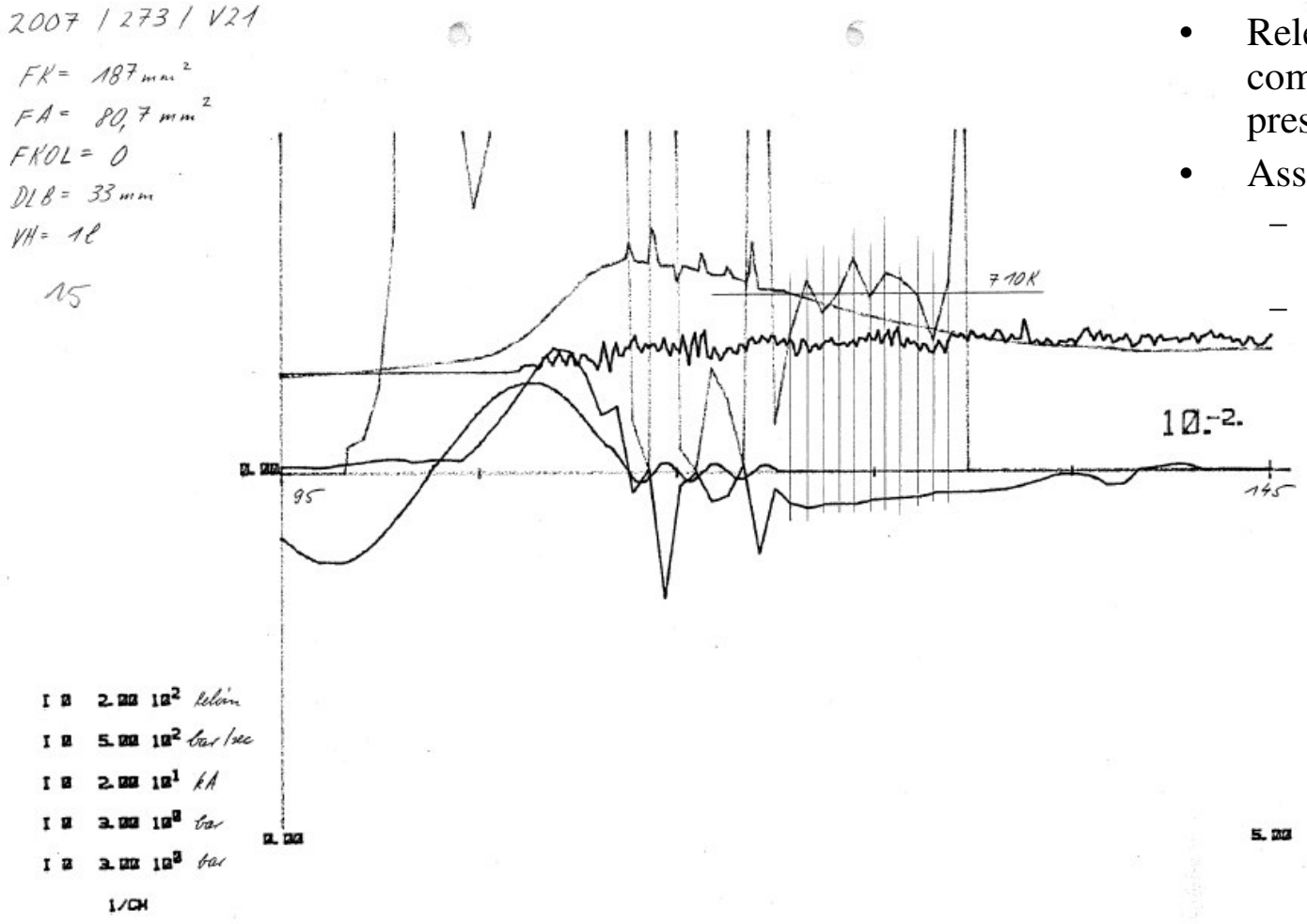
- Integral calculation program
- Running on workstations
- Definition of voluminas, drives, shapes etc. by means of points, connections volumes
- Changing topologies required programming effort
- Running time (CPU time) several minutes

Validation example-
Evaluation pressure temperature



- Relevant measured pressures compared with calcuated pressures at certain points
- Assumption:
  - If measured pressures fit with calculated pressures
  - Calculated temperatures are correct

Measurement pressure and temperature



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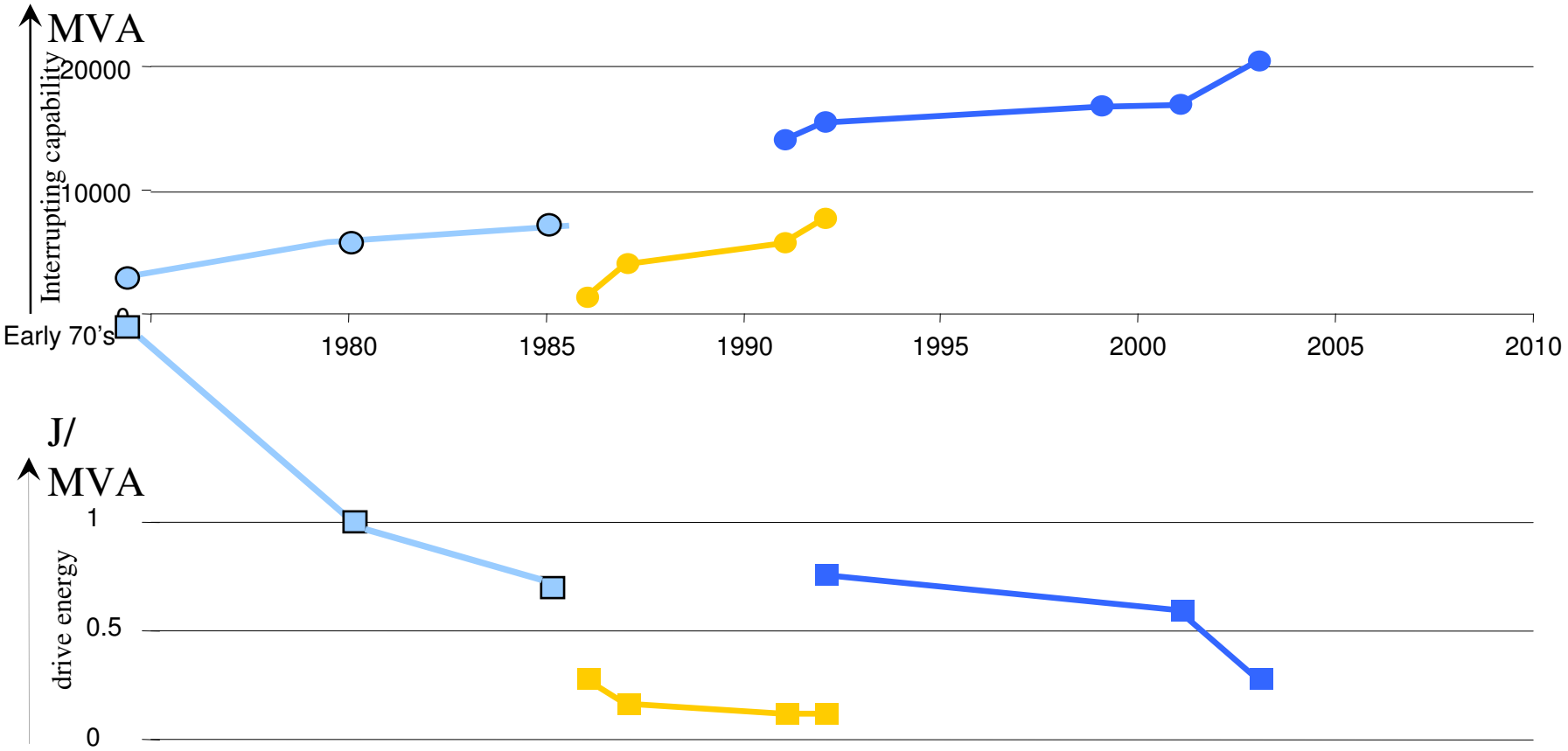
- Assumption:
  - If measured pressures fit with calculated pressures
  - Calculated temperatures are correct

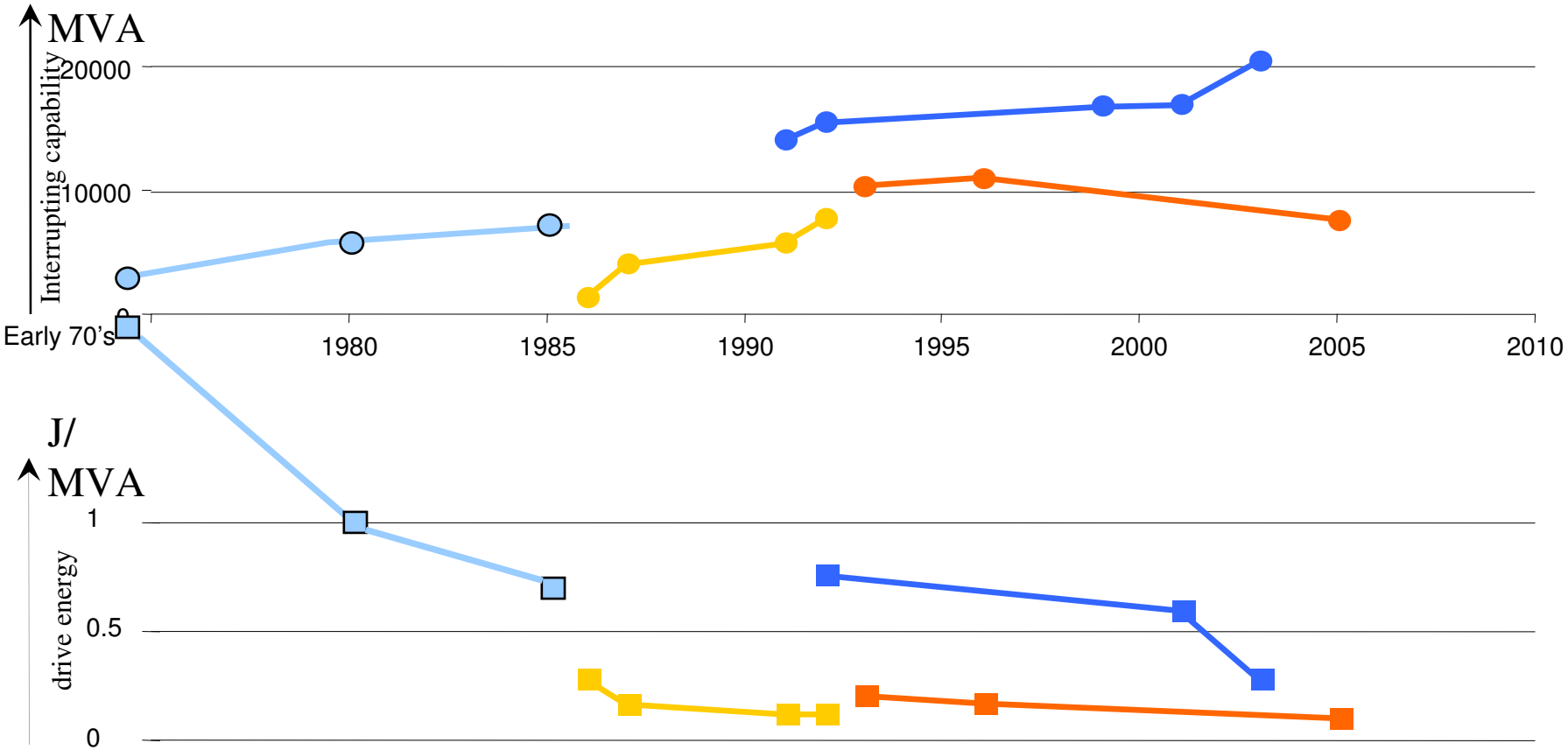
Overview SF_6-Circuit Breakers



3rd Generation: **Advanced Puffer Breaker**

- Extinguishing pressure generated from arc energy and cylinder-piston compression
- Reduction of needed drive energy
- Complex relation between geometry, switching case and arcing time

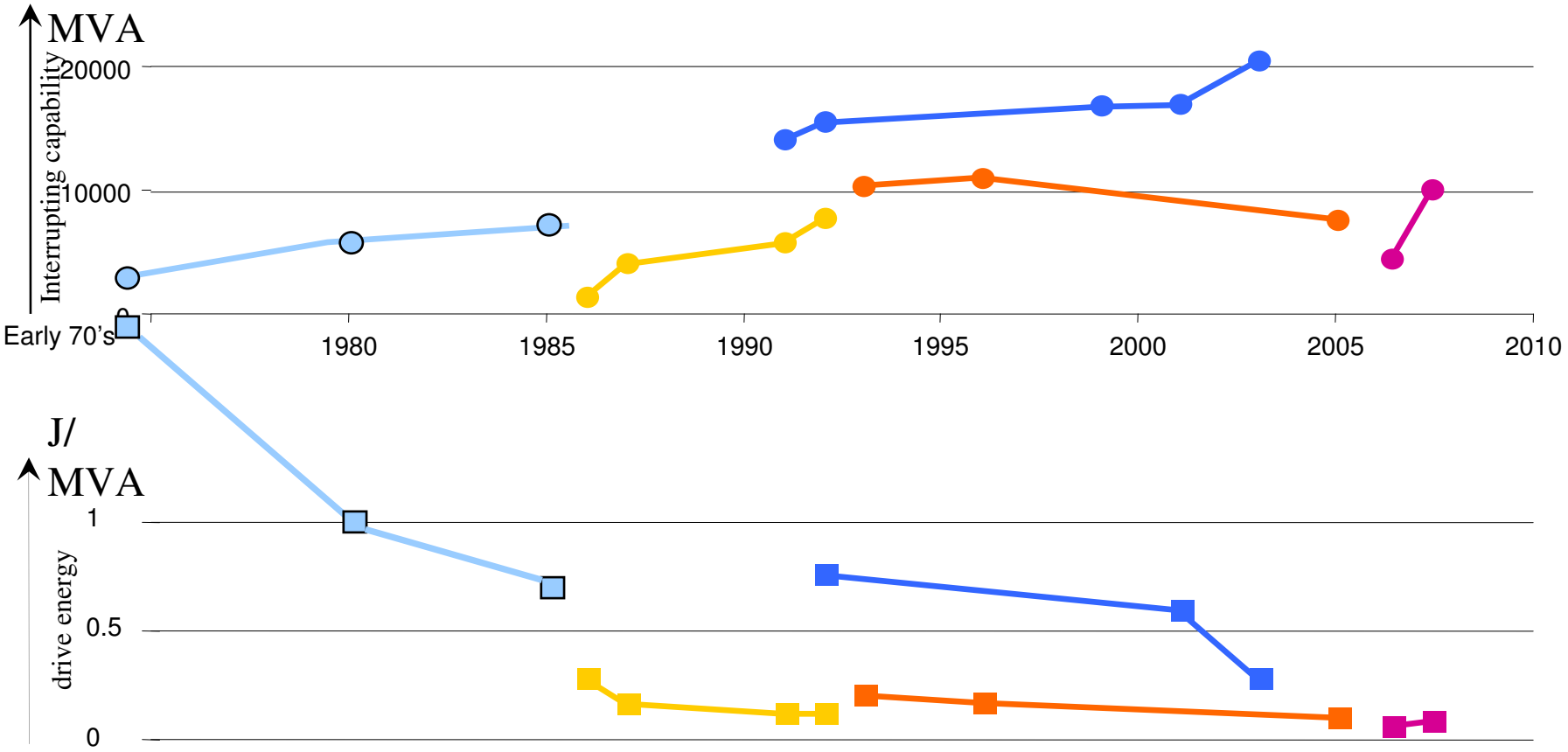
Overview SF_6-Circuit Breakers



4th Generation: **Double Linear Move Self Blast Breaker**

- Significant reduction of needed drive energy
- Required puffer speed is half the conventional speed

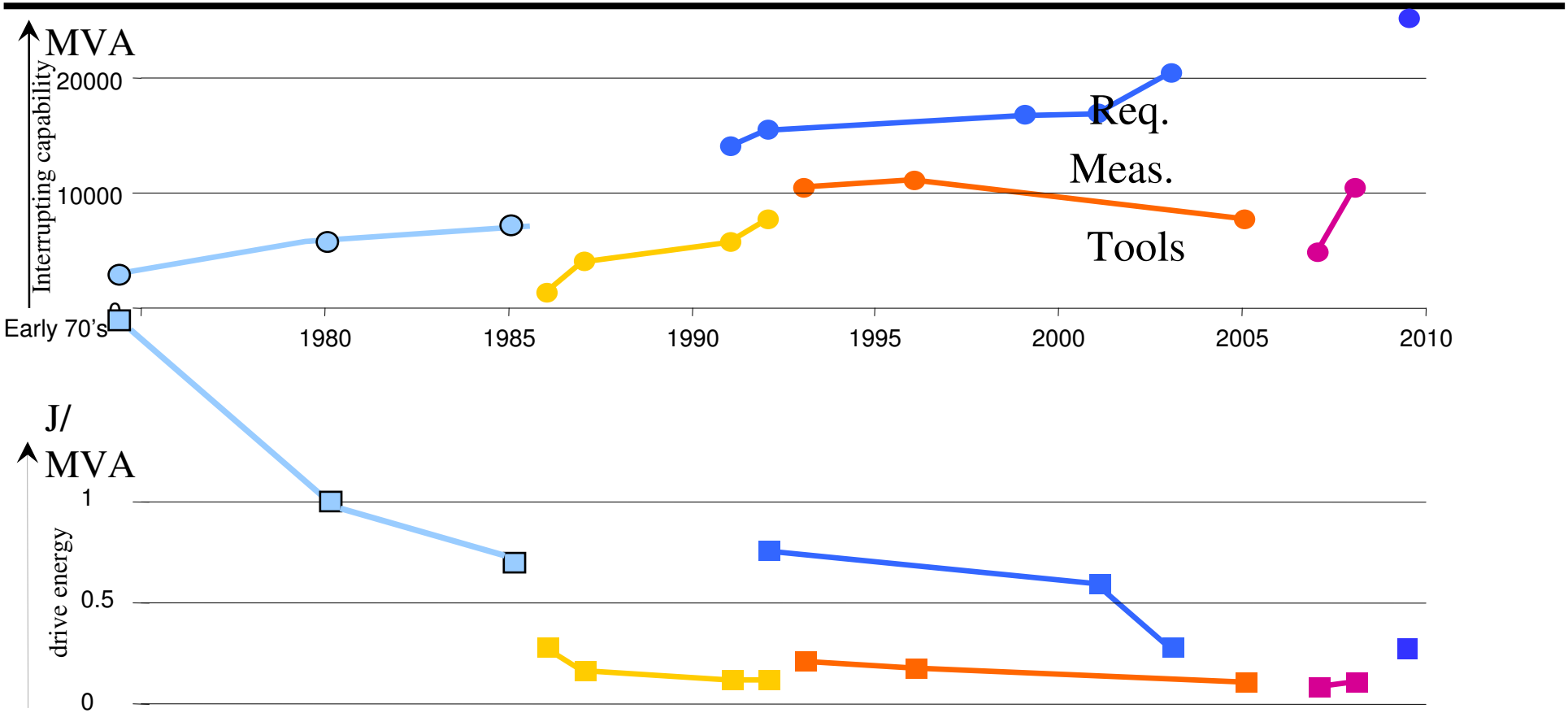
Overview SF_6-Circuit Breakers



5th Generation: **Non-Linear Double Move Self Blast Breaker**

- Even greater reduction of drive energy
- More complex relation between puffer and pin movement

Overview SF_6-Circuit Breakers



7th Generation: **Non Linear Puffer Breaker**

- Extinguishing pressure mainly generated from arc energy
- Cylinder-piston compression only for lower currents
- Significant reduction of needed drive energy

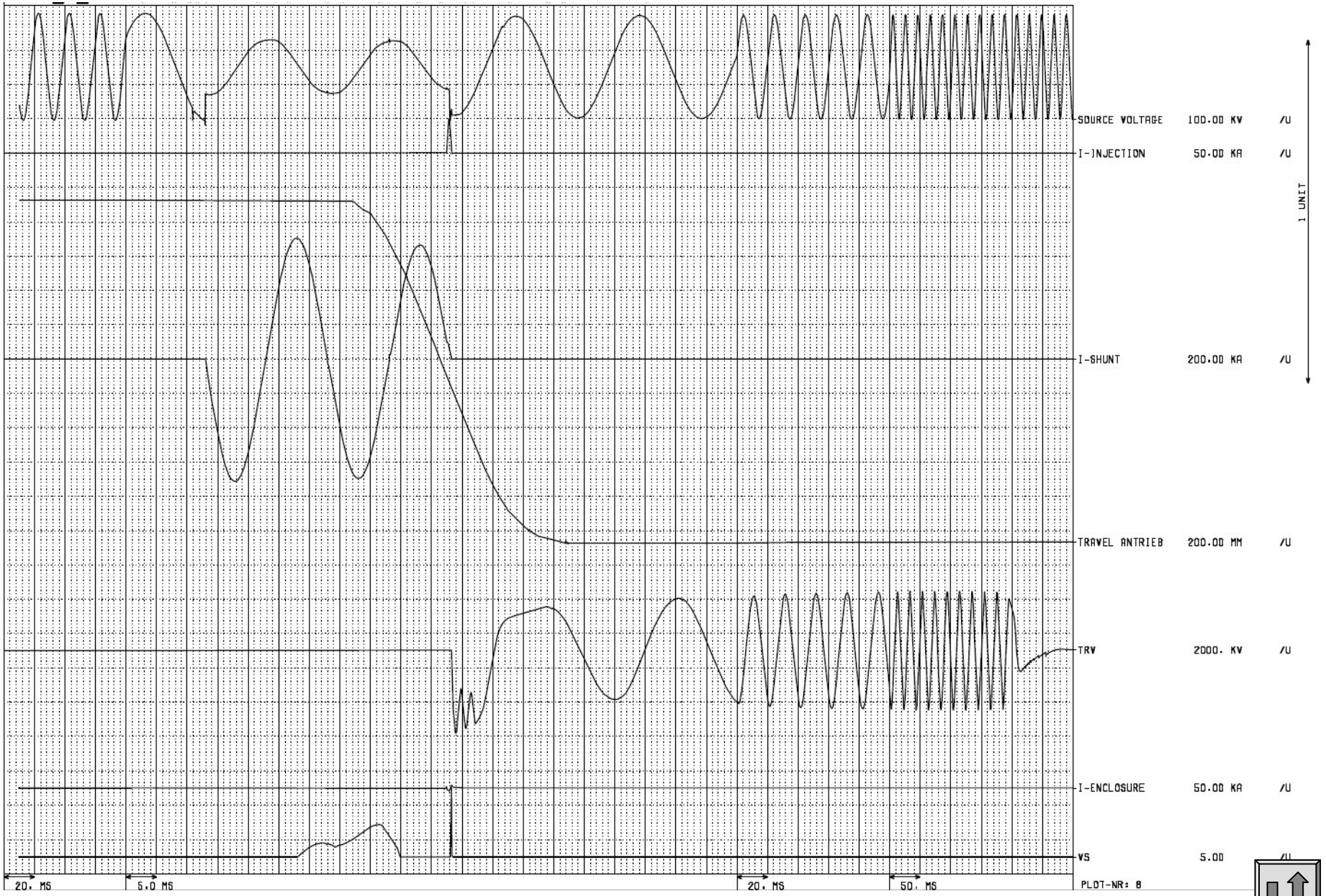
IEC standard mid 2001

- ITRV switching condition
- Cap switching tests splitted in
  - C1 (low probability of restrikes) 48 operations
  - C2 (very low probability of restrikes) 96 operations (with preconditioning)
  - Cap bank switching 168 operations
- Single phase and double earth fault tests described
- Condition check
- Alternative dc time constants introduced
- Mechanical endurance
  - M1 2000 operations
  - M2 10000 operations
- Electrical endurance E2

Measurements type tests 2000‘s

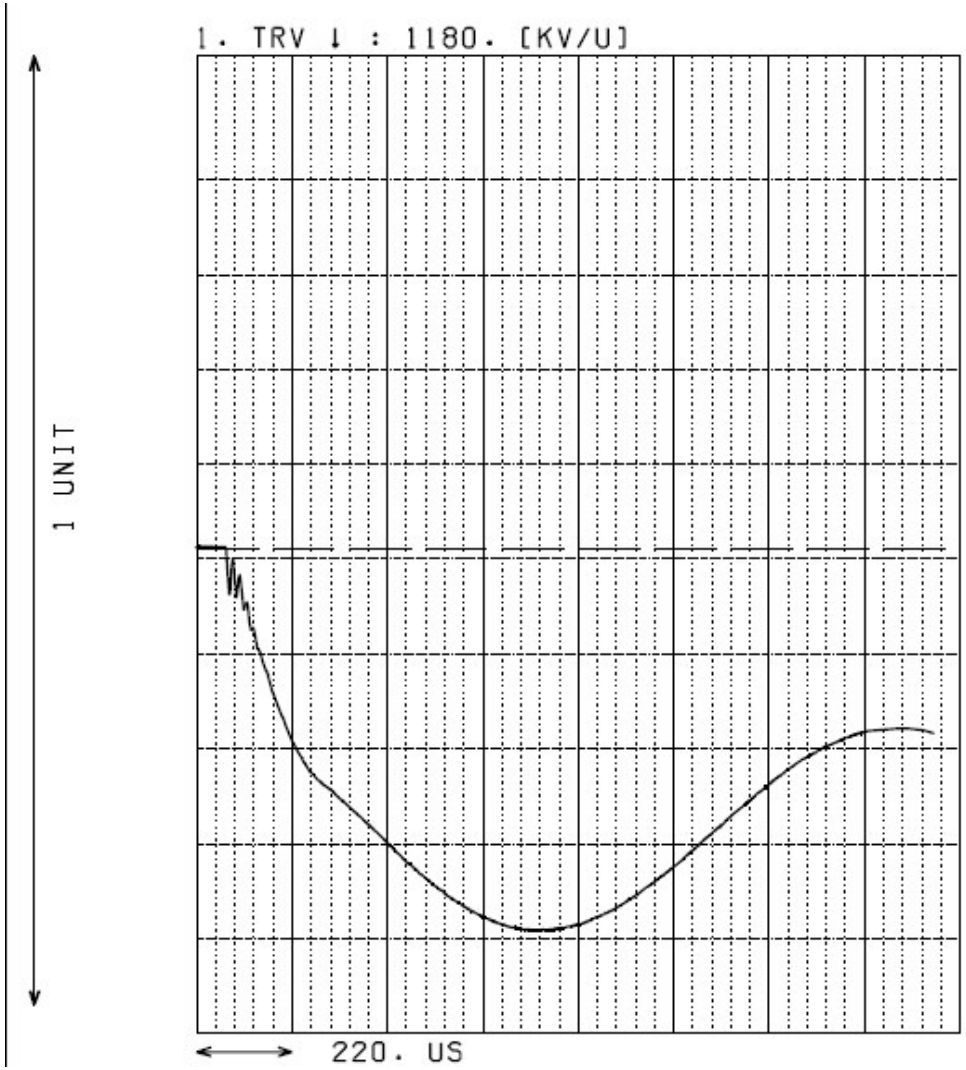
- Low speed
  - Digital transient recorders
- Medium speed
  - Digital transient recorders
- High speed
  - Digital transient recorders

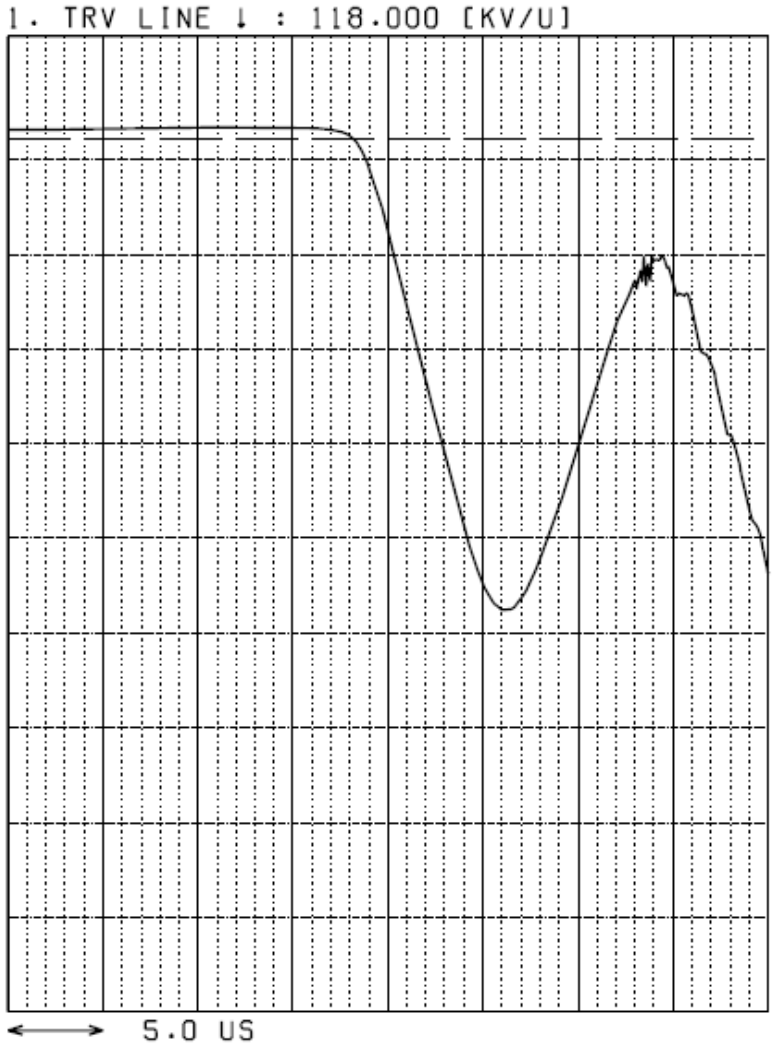
Overview Oscillogram 2



Current zero region

TRV Peak





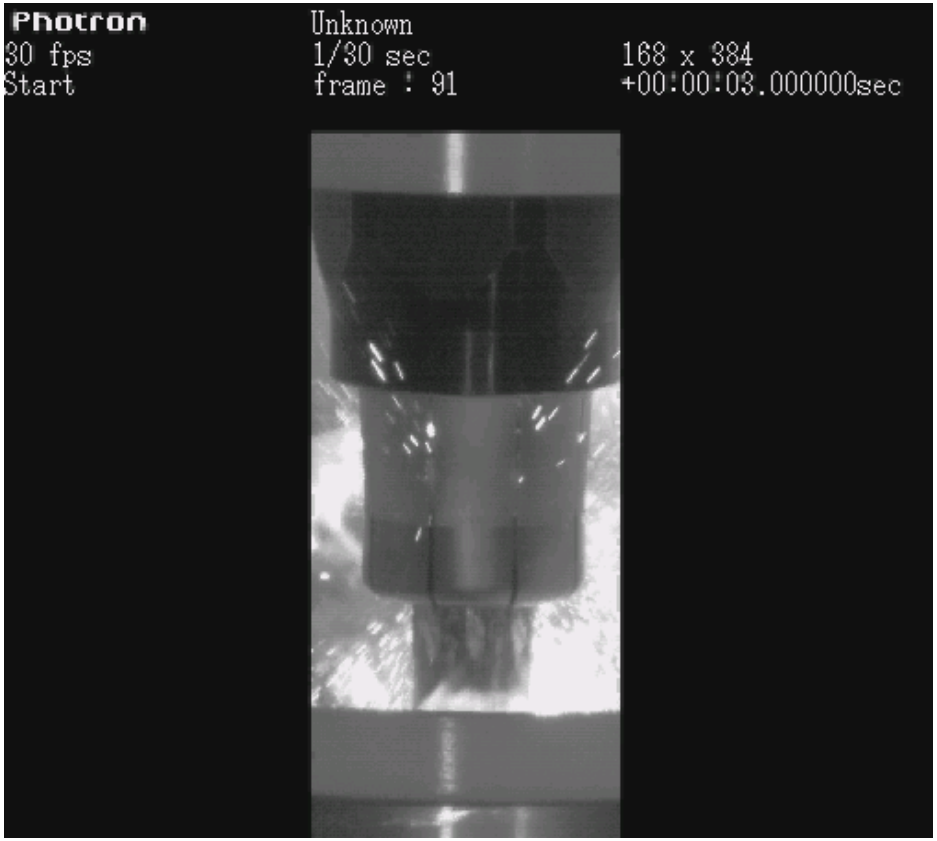
Measurements development tests 2000‘s

- Voltage
  - applied
  - Arcvoltage
  - TRV
- Current
  - Post arc current
- Travel on different locations (may be on potential)
- Pressure in different volumes (may be on potential)
- Forces at different locations (may be on potential)
- Temperatures
- High speed video movies

High speed video movies

- Closing at voltage zero

- Closing at voltage maximum



Calculation/simulation tools 2000‘s

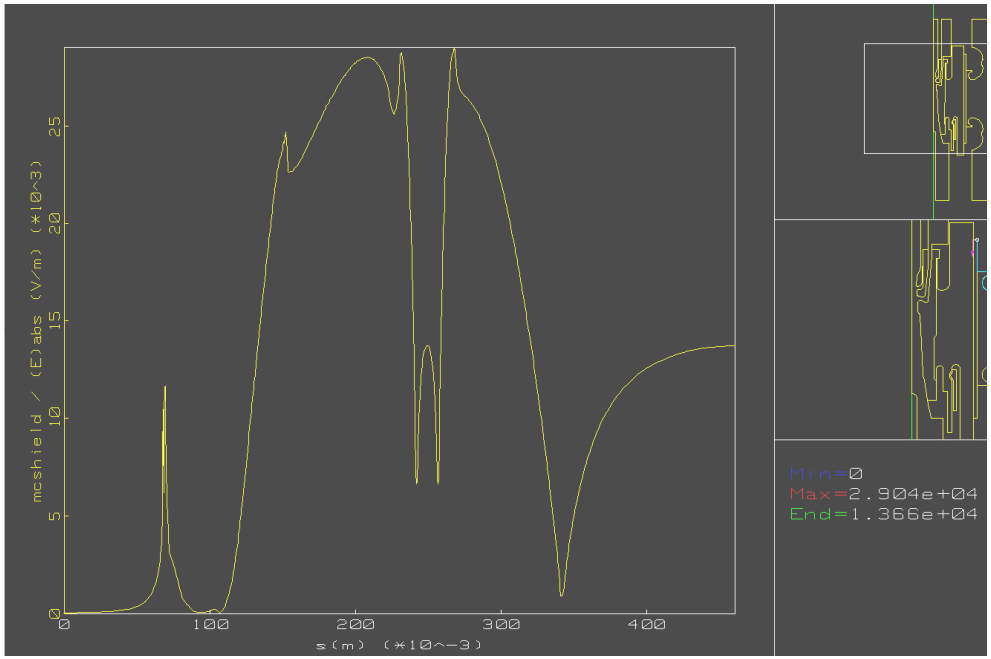
- Cold static Dielectric
  - 2D Finite element programs running on a PC
  - 3D Finite element programs running on a PC
- Hot dynamic Dielectric/flow
  - 2D Finite element programs running on a PC
  - 3D Finite element programs running on a PC
- Pressure build up
  - Integral simulation programms running on a PC
  - CFD programs running a workstation

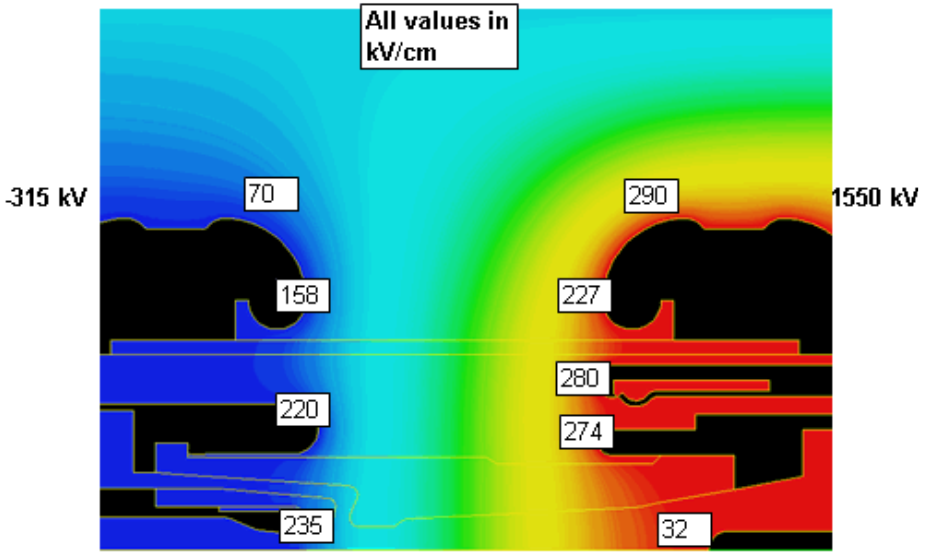
- Mechanical withstand capability
  - 2/3D Finite element programs running on a workstation

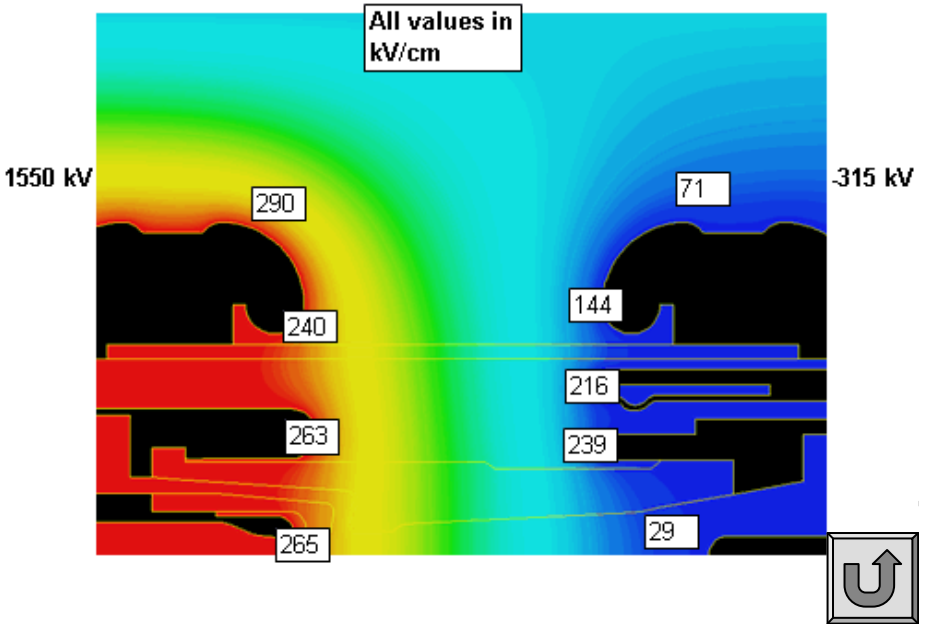
- **Al simulation tools may be coupled to simulate the complete circuit breaker (dynamic dielectric and mechanical behaviour)**

Static dielectric stress 2D

- Calculations
- Static 2 D
- Running on PC‘s
- Input geometry directly taken from (
- Calculation time some sec‘s

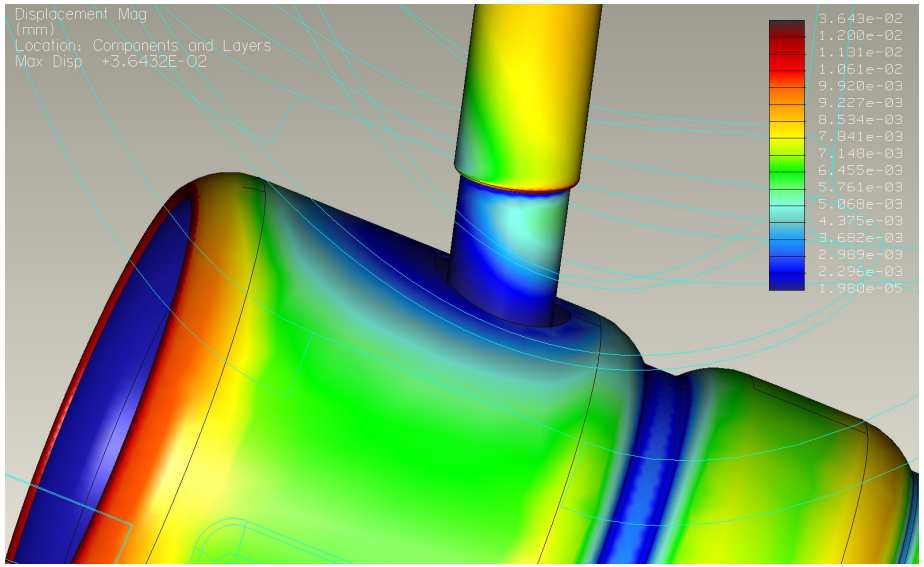


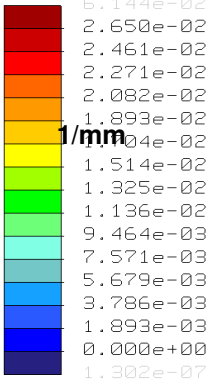


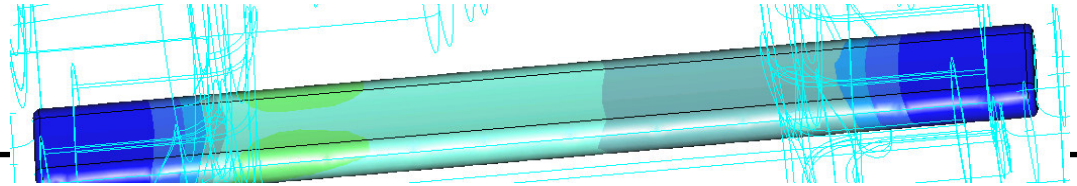


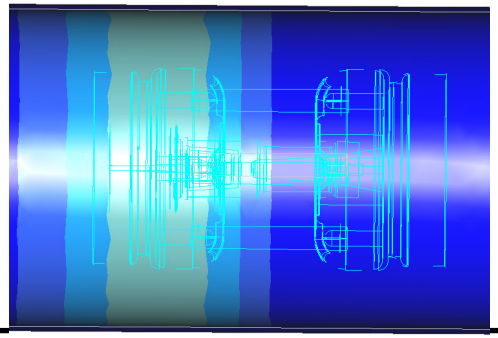
Static dielectric stress 3D

- Calculations
- Static 3 D
- Running on PC‘s
- Geometry directly taken from CAD systems



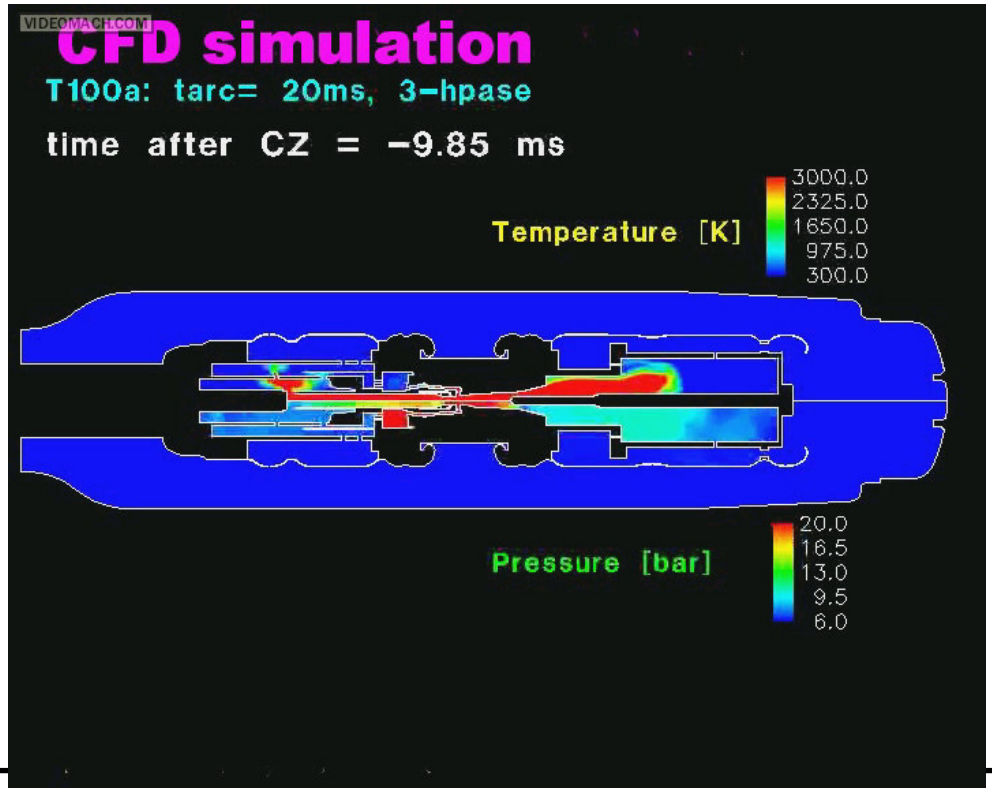






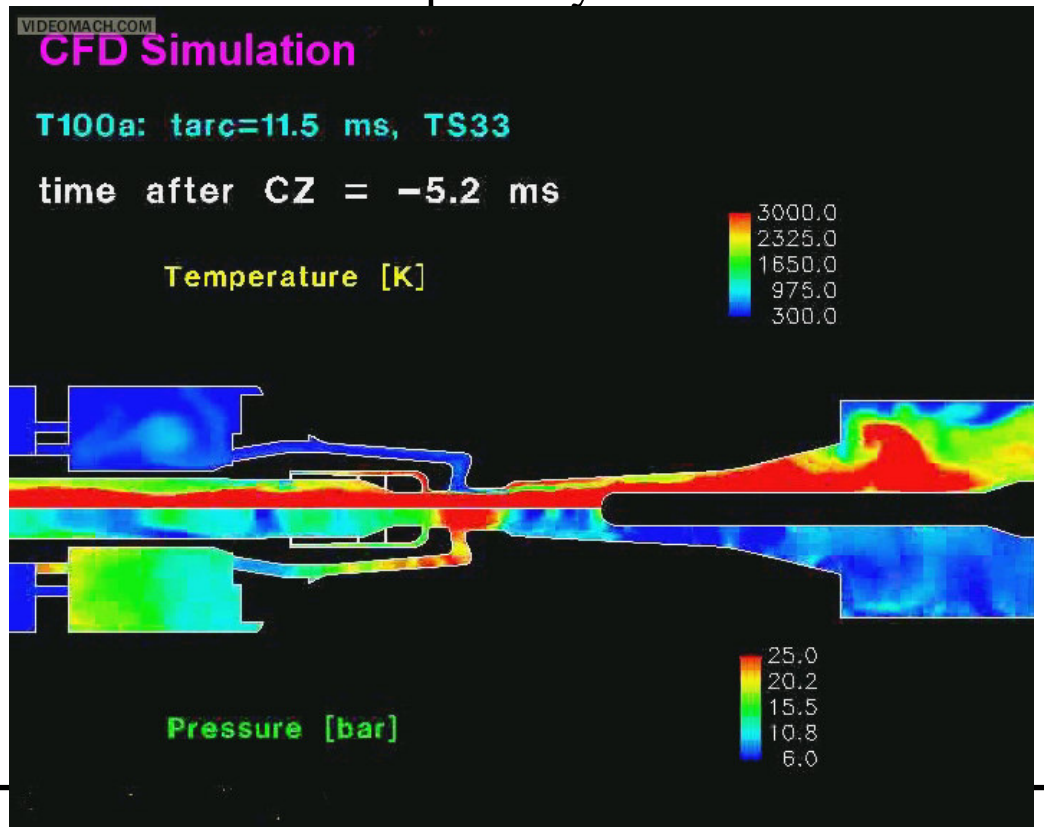
Flow calculation 2 D high complete breaker

- CFD (coupled with mech simulation)
- Running on workstations
- Geometrys directly taken from CAD
- Coupling also with electric field possibly
- Required CPU time several hours up to days



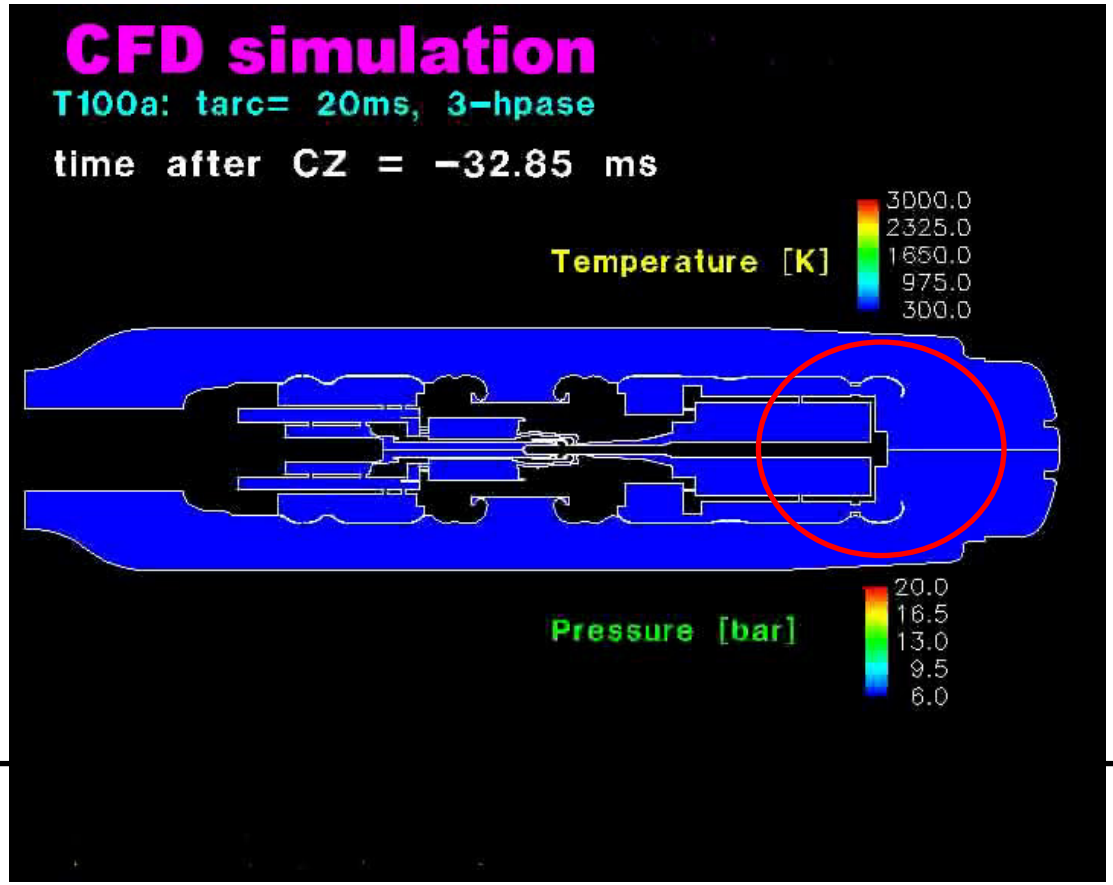
Flow calculation 2 D high current/nozzle system

- CFD (coupled with mech simulation)
- Running on workstations
- Geometrys directly taken from CAD
- Coupling also with electric field possibly
- Required CPU time several hours up to days



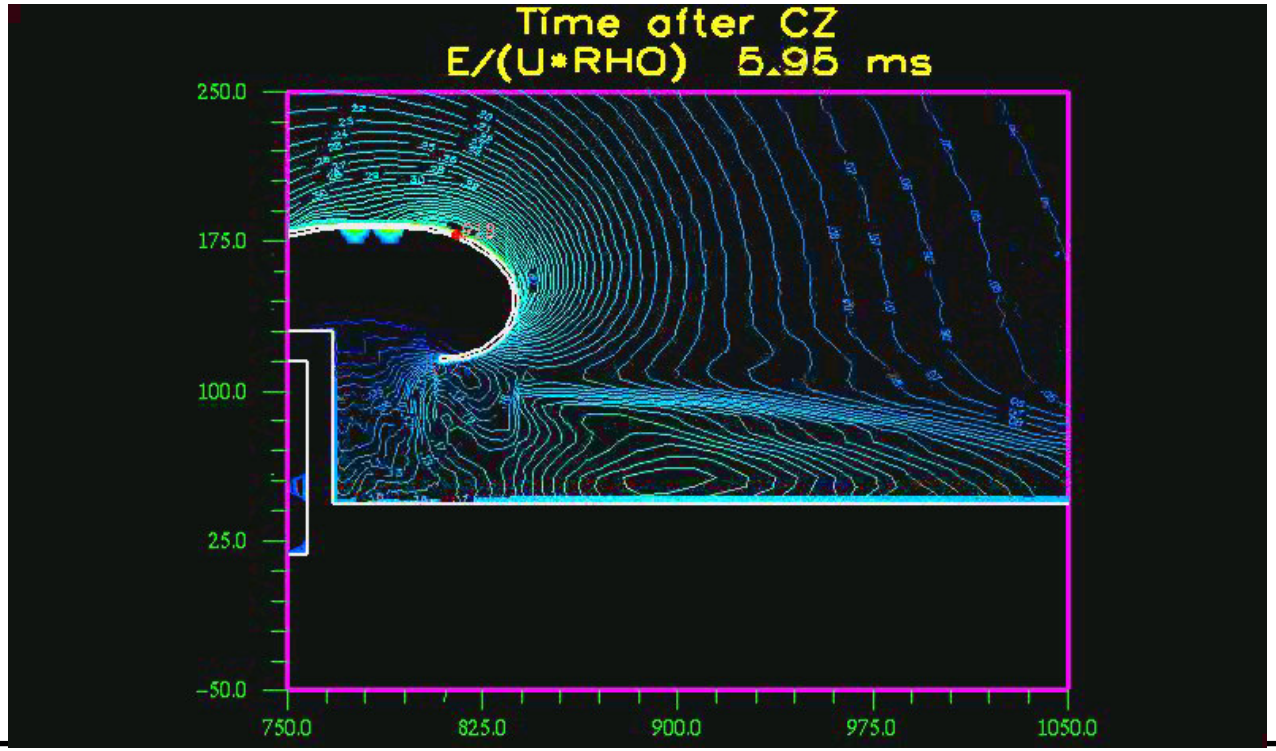
Flow calculation 2 D high current/exhaust

- CFD (coupled with mech simulation)
- Running on workstations
- Geometrys directly taken from CAD
- Coupling also with electric field possibly
- Required CPU time several hours up to days

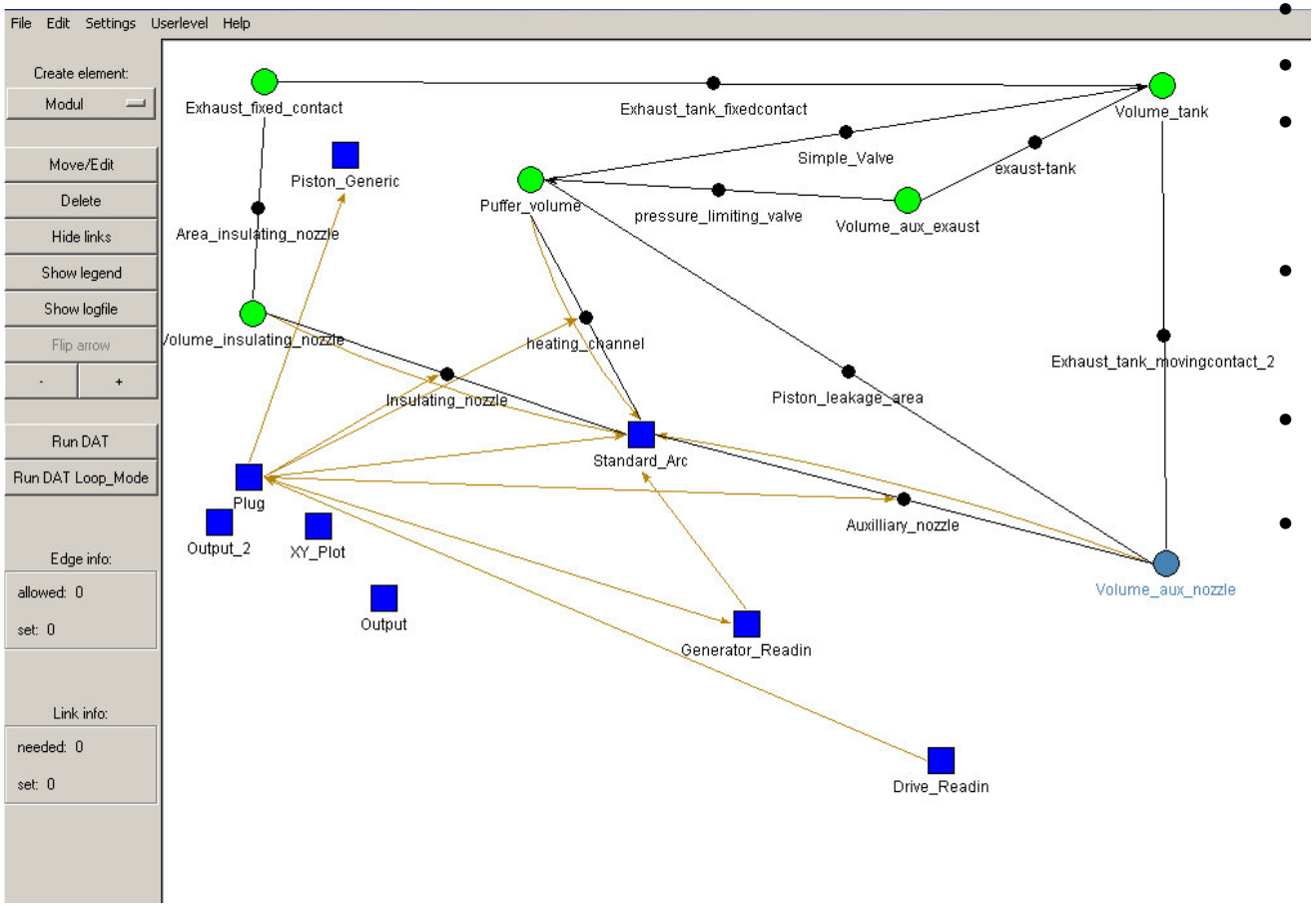


Flow calculation 2 D high current/exhaust

- CFD (coupled with mech simulation)
- Running on workstations
- Geometrys directly taken from CAD
- Coupling also with electric field possibly
- Required CPU time several hours up to days

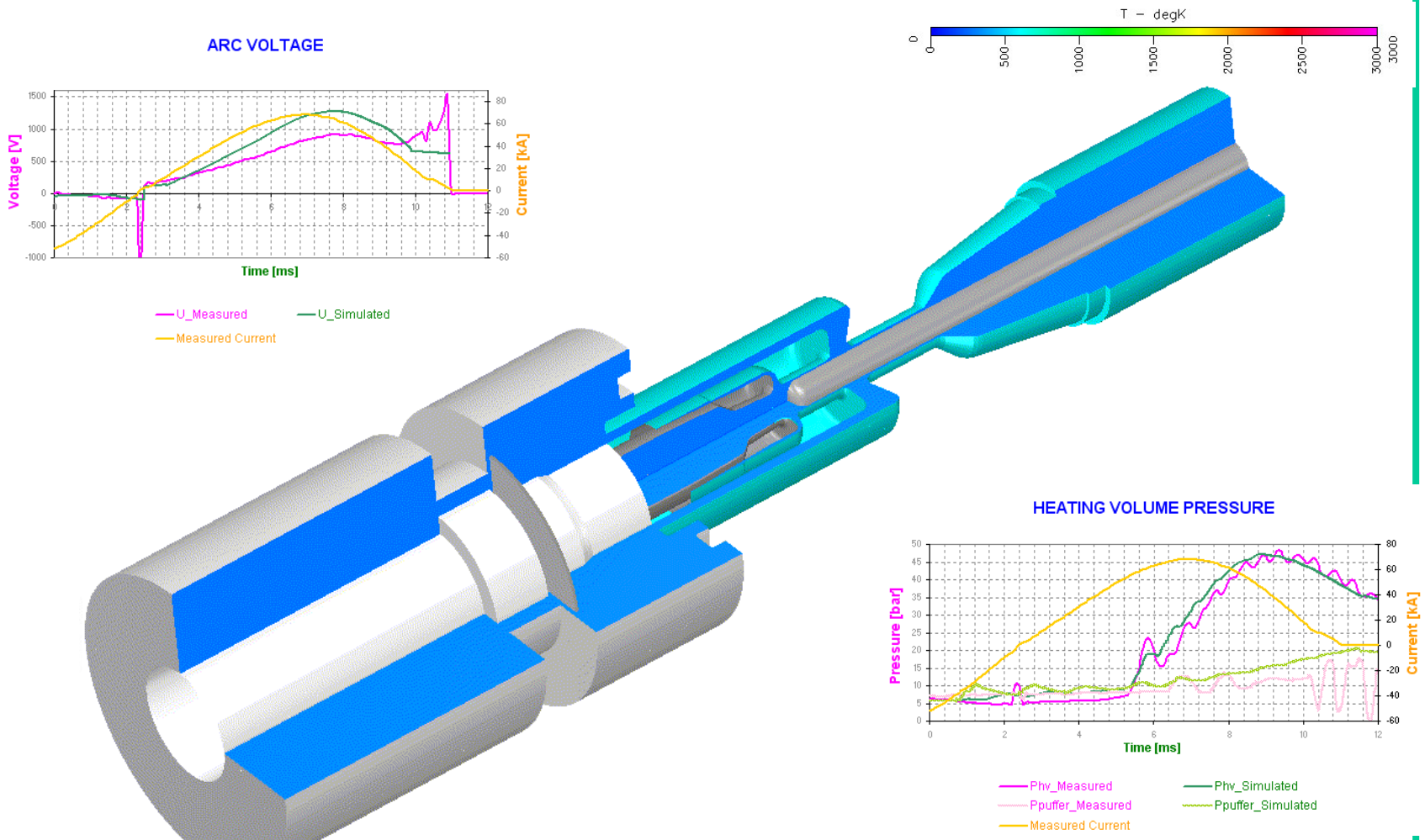


Pressure buildup calculation program (integral)



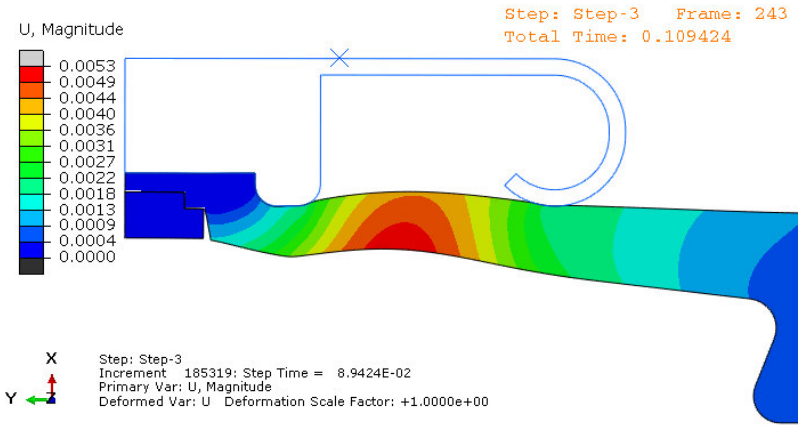
- Integral calculation program
- Running on PC‘s
- Definition of voluminas, drives, shapes etc. by means of points, connections volumes
- Definition of dependencies between the different items graphically
- Flexible with regard to geometries and dependencies
- Running time (CPU time) few sec.

Validation - Example



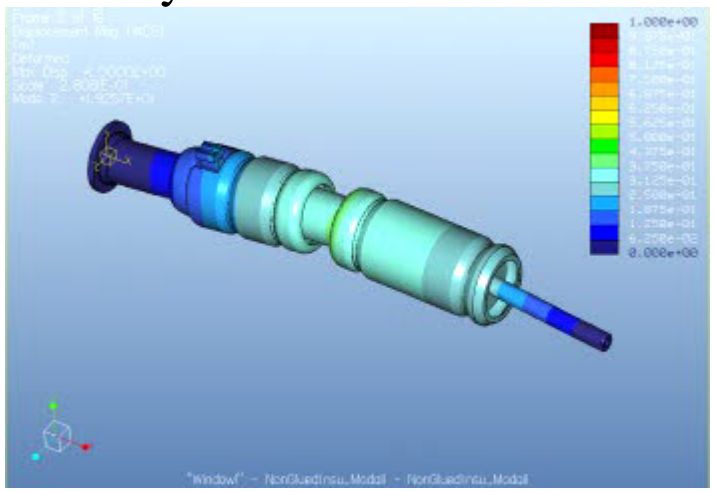
- Direct comparision of measured data with calculated data possible

Mechanical stress

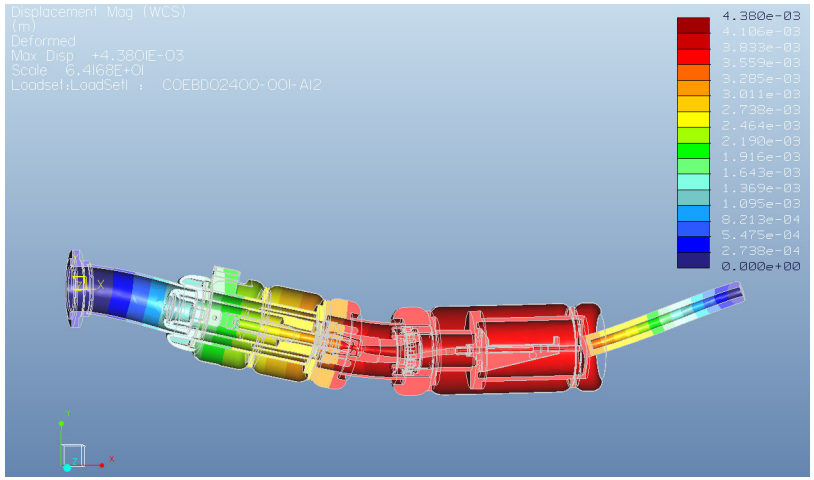


- Example stress on insulating nozzle

- Example natural frequency of pole assembly

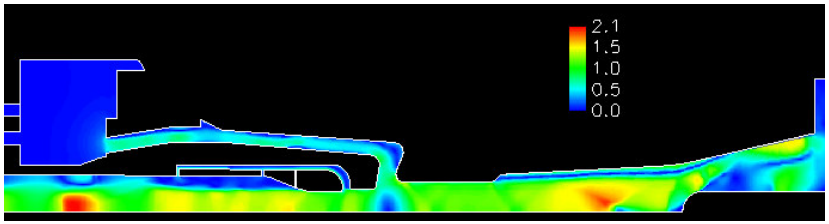


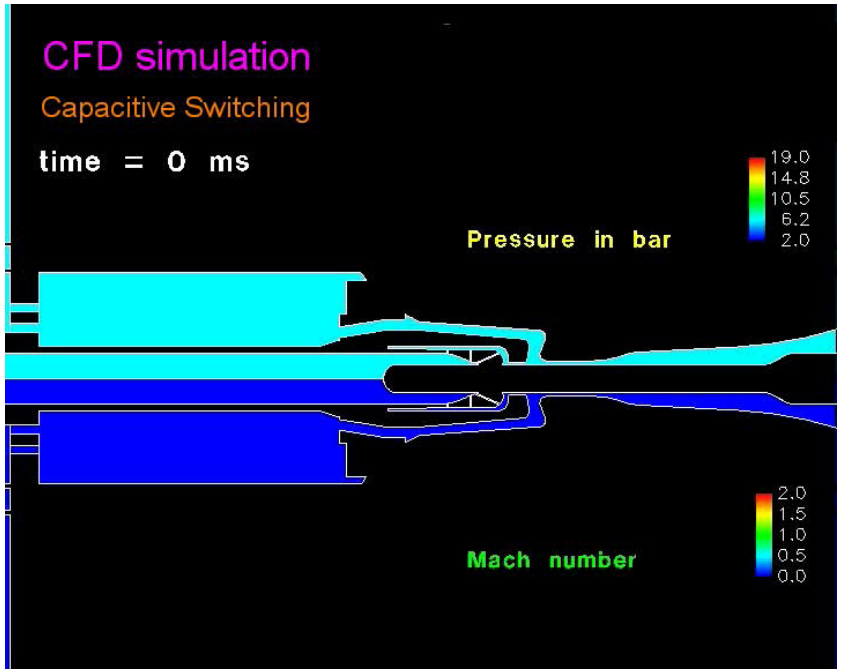
- Example bending forces during high current interruption

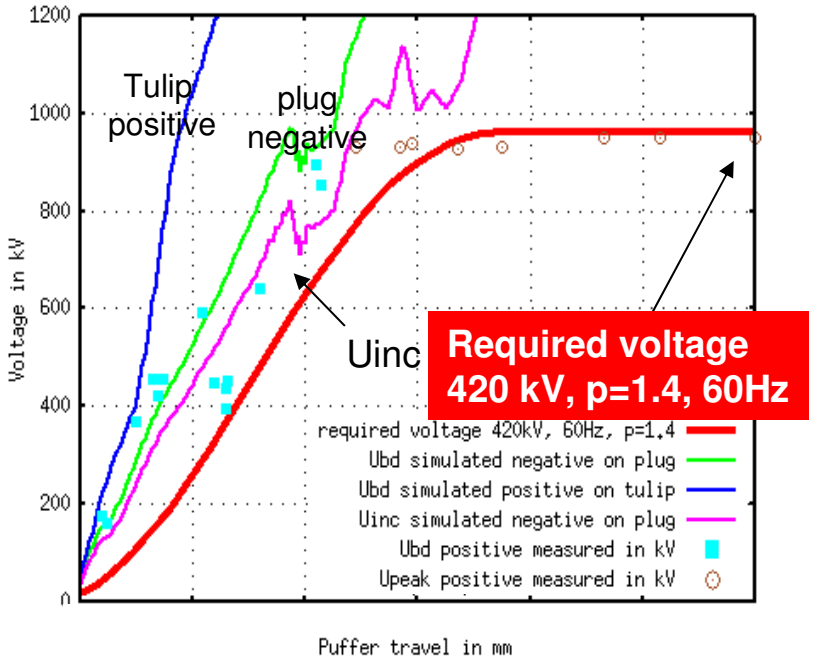


Flow calculation dynamic dielectric stress

- E/Rho calculations
- CFD combined with field calculations
- Running on workstations
- Required CPU time several hours

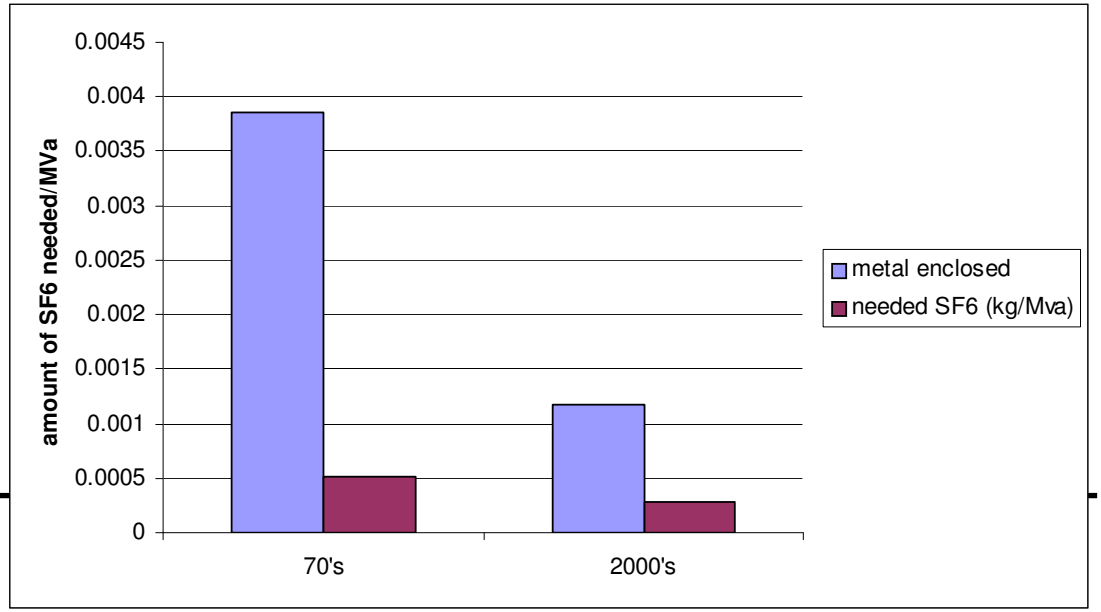






Summary

- The electrical switching capability per chamber increased more than 10 times
- The necessary drive energy decreased to less than one tenth
- The amount of used/needed SF6 decreased to approx 1/3



Thank you