

Auswertung

February 1, 2024

0.0.1 Vorbereitungen

yum install texlive-collection-latexextra texlive-collection-mathscience python-pip pandoc

pip install --user notebook pandas seaborn scipy

```
[1]: import math
import pandas as pd
import seaborn as sns
import numpy as np
from matplotlib import pyplot as plt
from scipy.stats import linregress
```

```
[2]: sns.set_theme(context='paper', style="whitegrid", color_codes=True)

plt.rcParams["axes.titlesize"] = 13 # default: 9
plt.rcParams["axes.labelsize"] = 13 # default: 9
plt.rcParams["legend.fontsize"] = 11 # default: 8.8
plt.rcParams["legend.title_fontsize"] = 11 # default: 8.8
plt.rcParams["xtick.labelsize"] = 11 # default: 8.8
plt.rcParams["ytick.labelsize"] = 11 # default: 8.8
```

```
[3]: H_column = r'$H$ in $\frac{A}{m}$'
I_column = r'$I_{\mathrm{max}}$ in A'
M_column = r'M in $10^6 \frac{A}{m}$'
```

```
[4]: def plot(data, hue_column=I_column, x_column=H_column, filename=None):
    img = sns.relplot(
        data=data,
        x=x_column,
        y=M_column,
        hue=hue_column,
        height=5,
        legend='full',
    )
    if filename is not None:
        img.figure.savefig(filename, bbox_inches='tight')
```

```
[5]: def subplot(data, x_column=H_column, y_column=M_column, axis=None):
    return sns.scatterplot(
        data=data,
        x=x_column,
        y=y_column,
        hue=I_column,
        marker='x',
        ax=axis
    )
```

Make symmetrical due to removing / adding an offset

```
[6]: def remove_offset(series):
    diff = series.max() + series.min()
    offset = diff/2
    print(f'offset {series.name}: {round(offset, 2)}')
    return series - offset
```

Making symmetrical is optional: Not wanted for Temperature graph

```
[7]: def H(df, I_max, n_p, offset=True):
    calc = df.copy()
    if offset:
        calc['H'] = remove_offset(calc['H'])

    U_max = calc['H'].abs().max()
    r = 1.5/100 # m
    return calc['H'].apply(lambda U: n_p/(2 * math.pi * r) * (I_max/U_max) * U)
```

```
[8]: def H_heizbar(df, I_max, offset=True):
    return H(df, I_max, n_p=17, offset=offset)
```

```
[9]: def H_spalt(df, I_max, offset=True):
    return H(df, I_max, n_p=54, offset=offset)
```

```
[10]: def M(df, offset=True):
    calc = df.copy()
    if offset:
        calc['M'] = remove_offset(calc['M'])

    nu = 50 # Hz
    n_s = 17
    q = 0.9/10_000 # m^2
    mu_0 = 4* math.pi * 1e-7
    return calc['M'].apply(lambda U: U / (47*4*nu*n_s*q*mu_0) / 1e6)
```

0.1 3.3.1

Overview

```
[11]: heizbar_a = pd.read_csv("3.3.1.a.csv", sep='\t')
      heizbar_b = pd.read_csv("3.3.1.b.csv", sep='\t')
      heizbar_c = pd.read_csv("3.3.1.c.csv", sep='\t')
      heizbar_d = pd.read_csv("3.3.1.d.csv", sep='\t')
```

```
[12]: heizbar_a[I_column] = r'3.00 $\pm$ 0.01'
      heizbar_a['Ringkern'] = 'ohne Spalt'
      heizbar_b[I_column] = r'1.00 $\pm$ 0.01'
      heizbar_c[I_column] = r'0.29 $\pm$ 0.01'
      heizbar_d[I_column] = r'0.10 $\pm$ 0.01'
```

```
[13]: heizbar_a[H_column] = H_heizbar(heizbar_a, I_max=3)
      heizbar_b[H_column] = H_heizbar(heizbar_b, I_max=1)
      heizbar_c[H_column] = H_heizbar(heizbar_c, I_max=0.29)
      heizbar_d[H_column] = H_heizbar(heizbar_d, I_max=0.1)

      heizbar_a[M_column] = M(heizbar_a)
      heizbar_b[M_column] = M(heizbar_b)
      heizbar_c[M_column] = M(heizbar_c)
      heizbar_d[M_column] = M(heizbar_d)
```

```
offset H: 0.03
offset H: 0.02
offset H: 0.03
offset H: 0.03
offset M: 0.08
offset M: 0.09
offset M: 0.11
offset M: 0.12
```

Alle Messungen in verschiedenen Plots

```
[14]: fig = plt.figure(figsize=(12,12))
      fig.subplots_adjust(hspace=0.4, wspace=0.4)

      # 4 subplots jeweils 1/2 Breite
      # https://matplotlib.org/stable/api/figure\_api.html#matplotlib.figure.Figure.
      ↪ add_subplot
      ax = fig.add_subplot(2, 2, 1)
      subplot(heizbar_a, axis=ax)

      ax = fig.add_subplot(2, 2, 2)
      subplot(heizbar_b, axis=ax)

      ax = fig.add_subplot(2, 2, 3)
      subplot(heizbar_c, axis=ax)

      ax = fig.add_subplot(2, 2, 4)
```

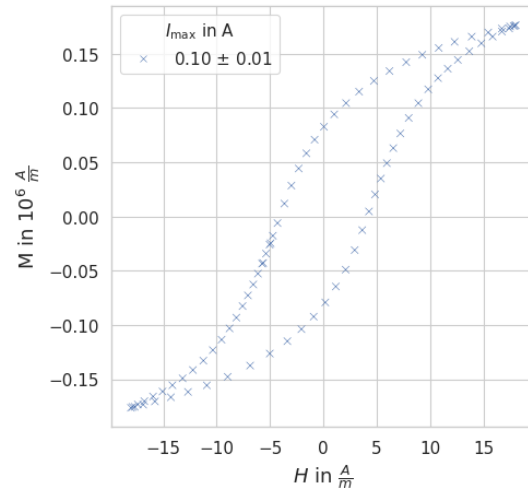
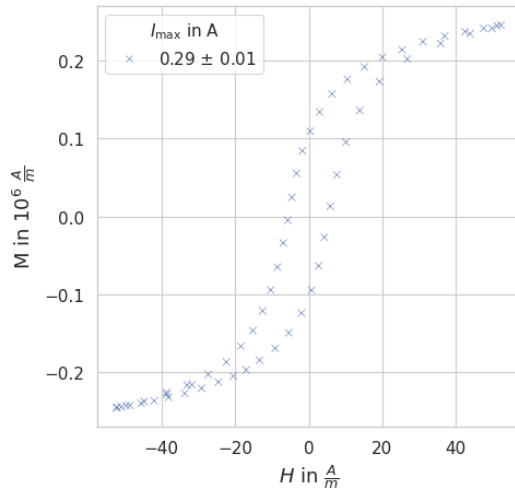
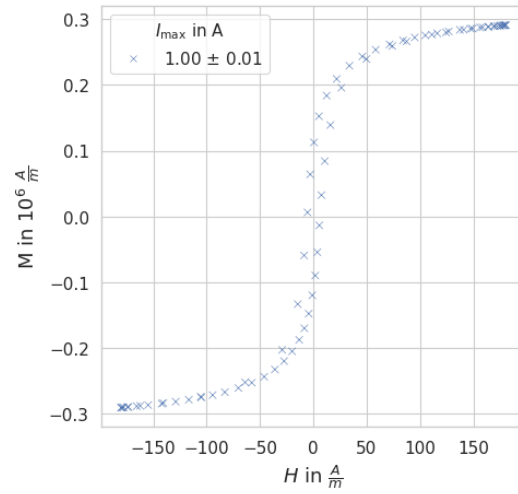
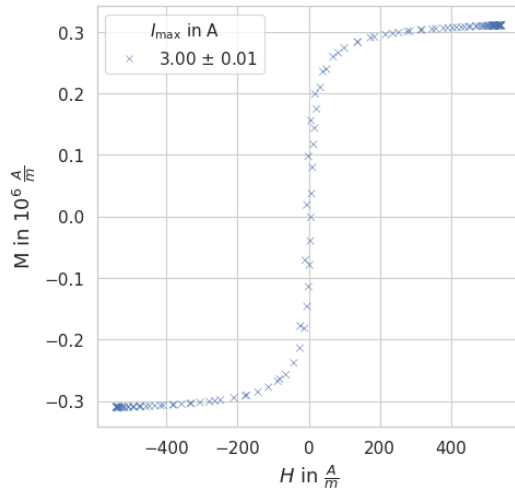
```

subplot(heizbar_d, axis=ax)

fig.savefig('../media/B2.4/3.3.1_single_measures.svg', bbox_inches='tight')

plt.show()

```



details & values

ermittle H_K threshold muss so gewählt werden, dass maximal 4 Werte herausgefiltert werden. Ideal wären zwei, falls ein Wert oben und ein Wert unten ist.

```

[15]: df = heizbar_b
      threshold = 0.03

```

```
df[df[M_column].abs() < threshold][[M_column, H_column]]
```

```
[15]:      M in  $10^6 \frac{A}{m}$    $H$  in  $\frac{A}{m}$ 
      31          0.006050      -5.495494
      65          -0.013589      5.608280
```

```
[16]: m = df[df[M_column].abs() < threshold][H_column].abs().mean()
      d = df[df[M_column].abs() < threshold][H_column].abs().std()
      print(m.round(2), r'&\pm', d.round(2), '&')
```

5.55 &\pm 0.08 &

ermittle Remanenz threshold muss so gewählt werden, dass maximal 3 Werte herausgefiltert werden. Ideal wären zwei, falls ein Wert oben und ein Wert unten ist.

Der Fehler muss mindestens das halbe Offset sein.

```
[17]: df = heizbar_a
      threshold = 2

      df[df[H_column].abs() < threshold][M_column]
```

```
[17]: 41      -0.114156
      124      0.097601
      Name: M in  $10^6 \frac{A}{m}$ , dtype: float64
```

```
[18]: m = df[df[H_column].abs() < threshold][M_column].abs().mean()
      d = df[df[H_column].abs() < threshold][M_column].abs().std()
      print(m.round(3), r'&\pm', d.round(3), '&')
```

0.106 &\pm 0.012 &

M_{\max} Der Fehler ist das Offset

```
[19]: df = heizbar_d
      m = (df[M_column].max() + abs(df[M_column].min()))/2
      print(m.round(2), r'&\pm', d.round(2))
```

0.18 &\pm 0.01

0.2 3.3.2

```
[20]: komm_a = pd.read_csv('3.3.2.a.csv', sep='\t')
      komm_b = pd.read_csv('3.3.2.b.csv', sep='\t')
```

```
[21]: komm_a[H_column] = H_heizbar(komm_a, I_max=3, offset=False)
      komm_b[H_column] = H_heizbar(komm_b, I_max=0.08, offset=False)
```

```
komm_a[M_column] = M(komm_a, offset=False)
komm_b[M_column] = M(komm_b, offset=False)
```

```
[22]: komm_a[I_column] = r'3.00 $\pm$ 0.01'
      komm_b[I_column] = r'0.10 $\pm$ 0.01'
```

```
[23]: komm_b = komm_b[komm_b[H_column] <= 0]
      # komm_b[H_column] *= -1
      # komm_b[M_column] *= -1
```

```
[24]: komm_a = komm_a.sort_values(by=H_column)
      komm_b = komm_b.sort_values(by=H_column)
```

```
[25]: x_range_a = np.linspace(komm_a[H_column].min(), komm_a[H_column].max(), 100)
      interp_a = np.interp(x_range_a, komm_a[H_column], komm_a[M_column])
```

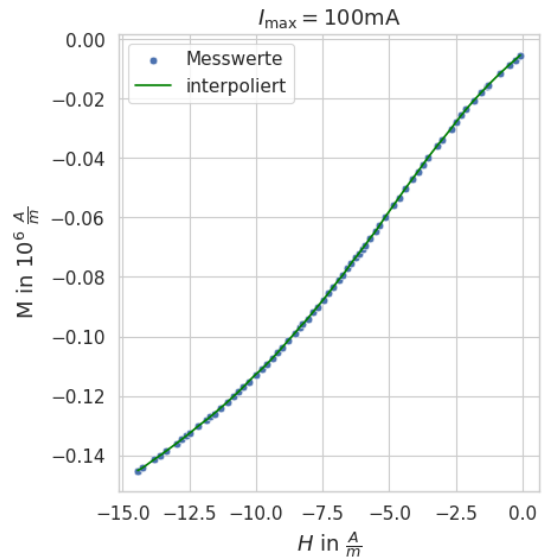
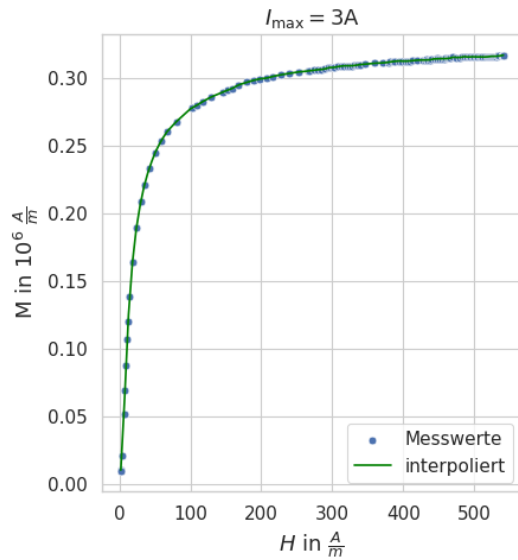
```
[26]: x_range_b = np.linspace(komm_b[H_column].min(), komm_b[H_column].max(), 100)
      interp_b = np.interp(x_range_b, komm_b[H_column], komm_b[M_column])
```

```
[27]: fig = plt.figure(figsize=(11,5))
      fig.subplots_adjust(wspace=0.4)

      ax = fig.add_subplot(1, 2, 1)
      plt.title(r'$I_{\mathrm{max}} = 3\text{A}$')
      sns.scatterplot(
          data=komm_a,
          x=H_column,
          y=M_column,
          ax=ax,
          label='Messwerte'
      )
      plt.plot(x_range_a, interp_a, color='green', label='interpoliert')
      plt.legend()

      ax = fig.add_subplot(1, 2, 2)
      plt.title(r'$I_{\mathrm{max}} = 100\text{mA}$')
      sns.scatterplot(
          data=komm_b,
          x=H_column,
          y=M_column,
          ax=ax,
          label='Messwerte'
      )
      plt.plot(x_range_b, interp_b, color='green', label='interpoliert')
      plt.legend()

      fig.savefig('../media/B2.4/3.3.2_Messung.svg', bbox_inches='tight')
```



Ableitung

```
[28]: _, y_a = np.gradient([x_range_a, interp_a])
      _, y_b = np.gradient([x_range_b, interp_b])

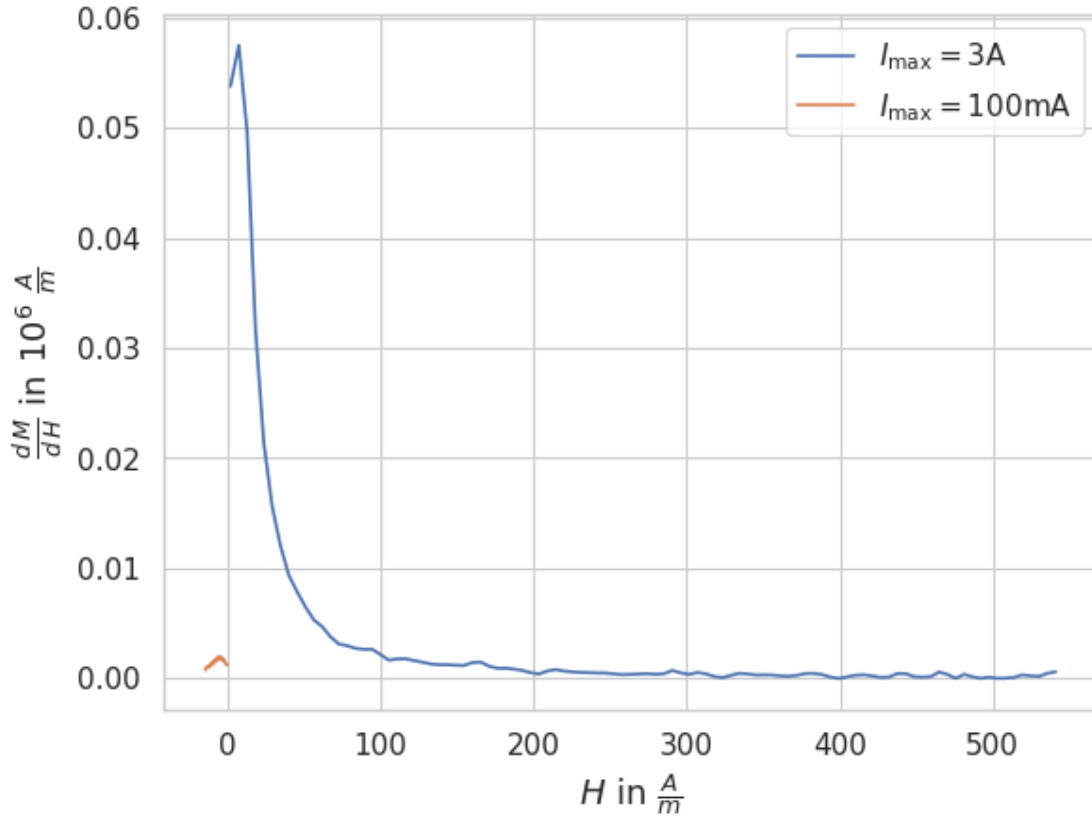
fig = plt.figure()

plt.plot(x_range_a, y_a[1], label=r'$I_{\mathrm{max}} = 3\mathrm{A}$')
plt.plot(x_range_b, y_b[1], label=r'$I_{\mathrm{max}} = 100\mathrm{mA}$')

plt.xlabel(H_column)
plt.ylabel(r'$\frac{dM}{dH}$ in $10^6 \frac{\mathrm{A}}{\mathrm{m}}$')

plt.legend()

fig.savefig('../media/B2.4/3.3.2_Ableitung.svg', bbox_inches='tight')
```



0.3 3.3.3

```
[29]: data = pd.read_csv('3.3.3.csv', sep='\t')
data[I_column] = r'3.00 $\pm$ 0.01'
T_column = r'T in $\sim$C'
data[T_column] = data['T']
data[M_column] = M(data, offset=False)
```

```
[30]: data
```

```
[30]:
```

	T	M \$I_{\mathrm{max}}\$ in A	T in \$\sim\$C \	
0	21.313081	5.581297	3.00 \$\pm\$ 0.01	21.313081
1	21.338784	5.580288	3.00 \$\pm\$ 0.01	21.338784
2	21.360401	5.579671	3.00 \$\pm\$ 0.01	21.360401
3	21.380637	5.578410	3.00 \$\pm\$ 0.01	21.380637
4	21.398098	5.578146	3.00 \$\pm\$ 0.01	21.398098
...
1790	80.715002	0.103282	3.00 \$\pm\$ 0.01	80.715002
1791	80.791621	0.104625	3.00 \$\pm\$ 0.01	80.791621
1792	80.869741	0.102399	3.00 \$\pm\$ 0.01	80.869741

1793	80.946711	0.101524	3.00	± 0.01	80.946711
1794	81.029722	0.100683	3.00	± 0.01	81.029722

	$M \text{ in } 10^6 \backslash \frac{A}{m}$
0	0.308820
1	0.308765
2	0.308730
3	0.308661
4	0.308646
...	...
1790	0.005715
1791	0.005789
1792	0.005666
1793	0.005617
1794	0.005571

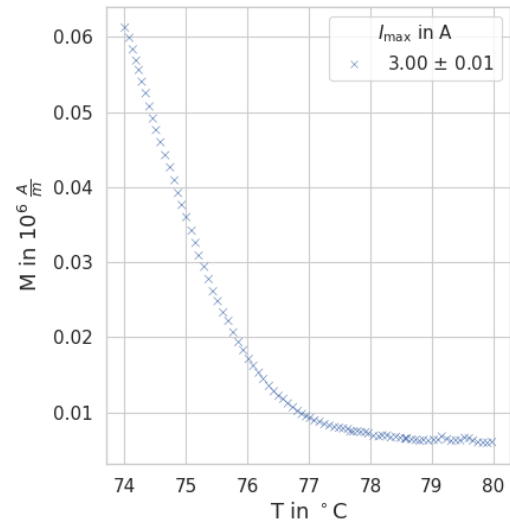
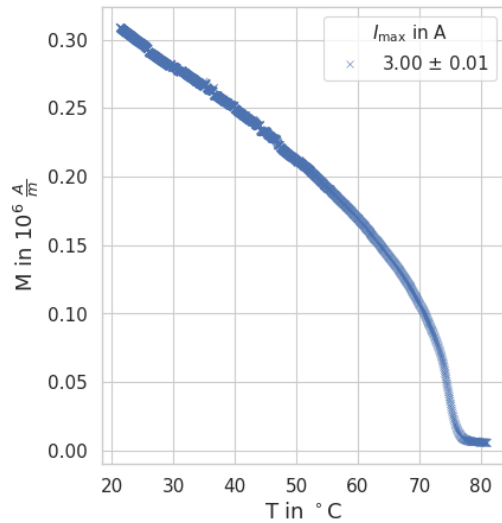
[1795 rows x 5 columns]

```
[31]: fig = plt.figure(figsize=(11,5))
fig.subplots_adjust(wspace=0.5)

ax = fig.add_subplot(1, 2, 1)
sns.scatterplot(
    data=data,
    x=T_column,
    y=M_column,
    hue=I_column,
    marker='x',
    legend='full',
    ax=ax
)

ax = fig.add_subplot(1, 2, 2)
sns.scatterplot(
    data=data[(data[T_column] > 74)&(data[T_column] < 80)],
    x=T_column,
    y=M_column,
    hue=I_column,
    marker='x',
    legend='full',
    ax=ax
)

fig.savefig('../media/B2.4/3.3.3.svg', bbox_inches='tight')
```



0.4 3.3.4

Messungsdetails: * 3.4.1: 0.94A * 3.4.2: 3.0A, 1mm * 3.4.3: 2.12A, 0.5mm * 3.4.4: 1.27A, 0.2mm
 * 3.4.5: 1.0A, 0.125mm * 3.4.6: 0.79A, 0.075mm * 3.4.7: 0.50A, 0.0mm

```
[32]: spalt_a = pd.read_csv('3.4.1.csv', sep='\t')
      spalt_b = pd.read_csv('3.4.2.csv', sep='\t')
      spalt_c = pd.read_csv('3.4.3.csv', sep='\t')
      spalt_d = pd.read_csv('3.4.4.csv', sep='\t')
      spalt_e = pd.read_csv('3.4.5.csv', sep='\t')
      spalt_f = pd.read_csv('3.4.6.csv', sep='\t')
      spalt_g = pd.read_csv('3.4.7.csv', sep='\t')
```

```
[33]: spalt_a[H_column] = H_spalt(spalt_a, I_max=0.94)
      spalt_b[H_column] = H_spalt(spalt_b, I_max=3.0)
      spalt_c[H_column] = H_spalt(spalt_c, I_max=2.12)
      spalt_d[H_column] = H_spalt(spalt_d, I_max=1.27)
      spalt_e[H_column] = H_spalt(spalt_e, I_max=1.0)
      spalt_f[H_column] = H_spalt(spalt_f, I_max=0.79)
      spalt_g[H_column] = H_spalt(spalt_g, I_max=0.5)

      spalt_a[M_column] = M(spalt_a)
      spalt_b[M_column] = M(spalt_b)
      spalt_c[M_column] = M(spalt_c)
      spalt_d[M_column] = M(spalt_d)
      spalt_e[M_column] = M(spalt_e)
      spalt_f[M_column] = M(spalt_f)
      spalt_g[M_column] = M(spalt_g)
```

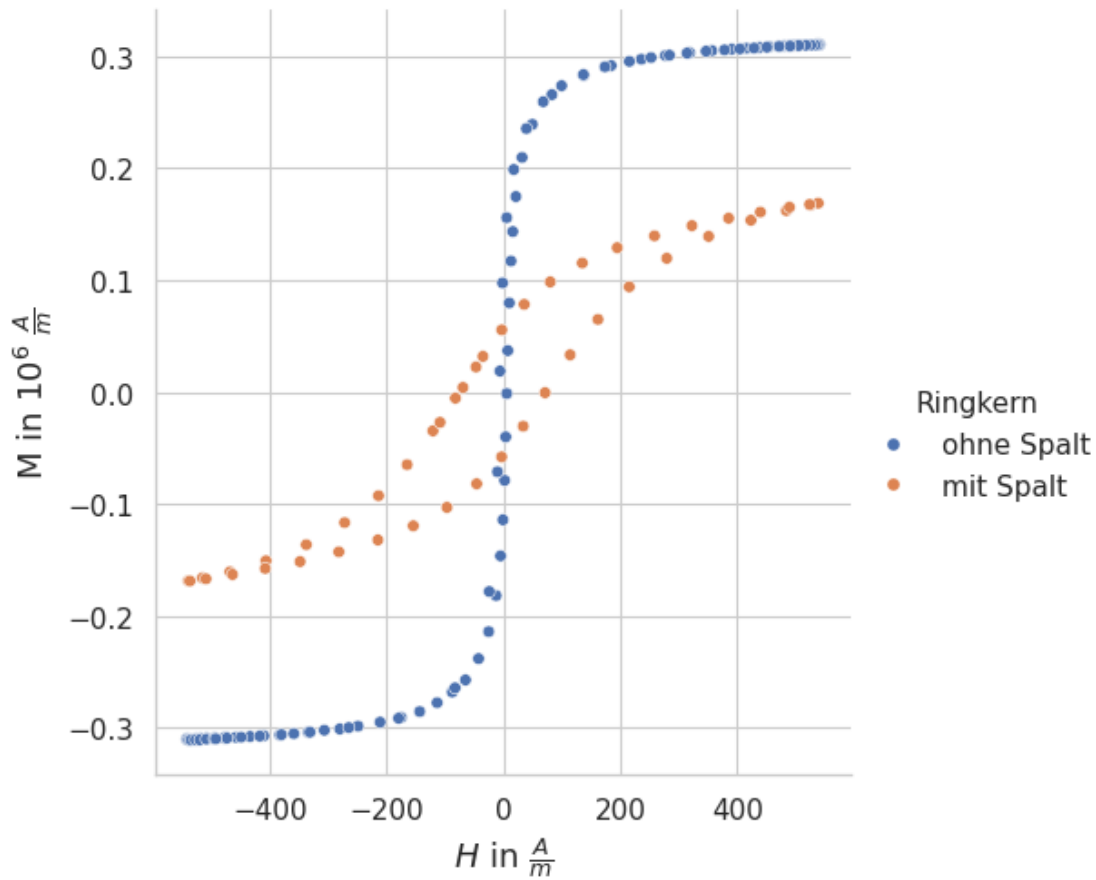
```
offset H: 0.03
offset H: 0.01
offset H: 0.02
offset H: 0.02
offset H: 0.03
offset H: 0.03
offset H: 0.03
offset M: 0.07
offset M: 0.06
offset M: 0.07
offset M: 0.07
offset M: 0.07
offset M: 0.08
offset M: 0.08
```

```
[34]: spalt_a['Ringkern'] = 'mit Spalt'

S_column = 'Spaltbreite'
spalt_a[S_column] = 'I_max=0.94A'
spalt_b[S_column] = r'2.00 mm'
spalt_c[S_column] = r'1.00 mm'
spalt_d[S_column] = r'0.40 mm'
spalt_e[S_column] = r'0.25 mm'
spalt_f[S_column] = r'0.15 mm'
spalt_g[S_column] = r'0.00 mm'
```

Vergleich

```
[35]: plot(pd.concat([heizbar_a, spalt_a]), hue_column='Ringkern', filename='../..//
↳media/B2.4/3.3.3_comparison.svg')
```



ermittle H_K threshold muss so gewählt werden, dass maximal 4 Werte herausgefiltert werden. Ideal wären zwei, falls ein Wert oben und ein Wert unten ist.

```
[36]: df = spalt_a
threshold = 0.02

df[df[M_column].abs() < threshold][[M_column, H_column]]
```

```
[36]:      M in  $10^6 \frac{A}{m}$     $H$  in  $\frac{A}{m}$ 
1          -0.005407          -81.824034
23         -0.000530           71.580132
45          0.004108          -68.855246
```

```
[37]: m = df[df[M_column].abs() < threshold][H_column].abs().mean()
d = df[df[M_column].abs() < threshold][H_column].abs().std()
print(m.round(2), r'\pm', d.round(2))
```

```
74.09 \pm 6.84
```

ermittle Remanenz `threshold` muss so gewählt werden, dass maximal 3 Werte herausgefiltert werden. Ideal wären zwei, falls ein Wert oben und ein Wert unten ist.

Der Fehler muss mindestens das halbe Offset sein.

```
[38]: df = spalt_a
      threshold = 3

      df[df[H_column].abs() < threshold][M_column]
```

```
[38]: 21    -0.057914
      43     0.055622
      Name: M in  $10^{-6} \frac{A}{m}$ , dtype: float64
```

```
[39]: m = df[df[H_column].abs() < threshold][M_column].abs().mean()
      d = df[df[H_column].abs() < threshold][M_column].abs().std()
      print(m.round(3), r'&\pm', d.round(3))
```

```
0.057 &\pm 0.002
```

M_{\max} Der Fehler ist das Offset.

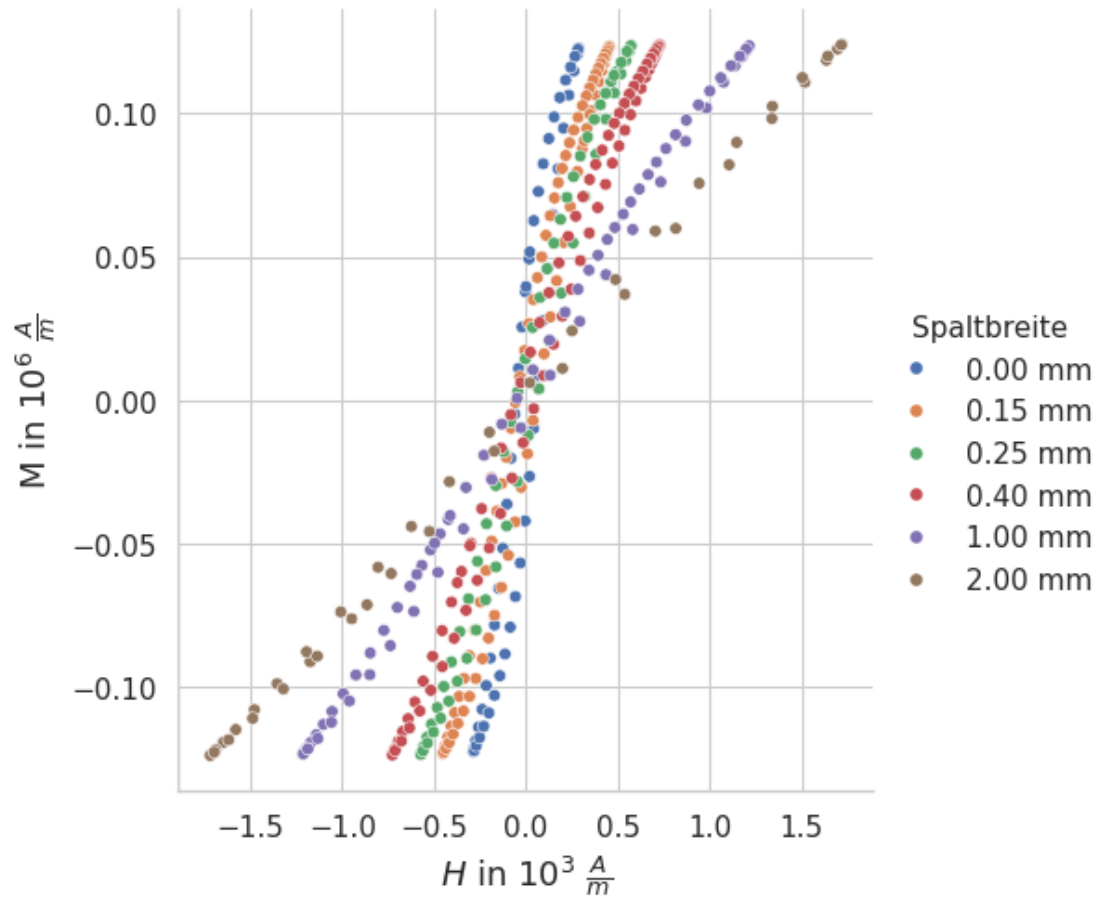
```
[40]: df = spalt_a
      m = (df[M_column].max() + abs(df[M_column].min()))/2
      d = (df[M_column].max() - abs(df[M_column].min()))/2
      print(m.round(3), r'&\pm', d.round(3))
```

```
0.169 &\pm 0.0
```

Entmagnetisierungsfaktor

```
[41]: H_column_rough = r'$H$ in  $10^{-3} \frac{A}{m}$ '
      spalt_all = pd.concat([spalt_g, spalt_f, spalt_e, spalt_d, spalt_c, spalt_b])
      spalt_all[H_column_rough] = spalt_all[H_column] / 1000

      plot(spalt_all, x_column=H_column_rough, hue_column=S_column, filename='.././media/B2.4/3.3.3_overview.svg')
```



Entmagnetisierungsfelder Der Fehler ist das halbe Offset

```
[42]: # offset b H: 0.01
      # offset c H: 0.02
      # offset d H: 0.02
      # offset e H: 0.03
      # offset f H: 0.03
      # offset g H: 0.03
```

H_{ent}

```
[43]: df = spalt_b

avg = (df[H_column].max() - spalt_g[H_column].max() - (df[H_column].min() -
↳ spalt_g[H_column].min()))/2e3
err = abs((df[H_column].max() - spalt_g[H_column].max() + (df[H_column].min() -
↳ spalt_g[H_column].min()))/2e3)
print(df['Spaltbreite'][0])
```

```
print(avg.round(2), r'\pm', err.round(2), '&')
```

2.00 mm

1.43 &\pm 0.0 &

M_{\max} Der Fehler ist der Offset

```
[44]: # offset b M: 0.06
      # offset c M: 0.07
      # offset d M: 0.07
      # offset e M: 0.07
      # offset f M: 0.08
      # offset g M: 0.08
```

```
[45]: df = spalt_g
      m = (df[M_column].max() + abs(df[M_column].min()))/2
      d = (df[M_column].max() - abs(df[M_column].min()))/2
      print(df['Spaltbreite'][0])
      print(m.round(2), r'\pm', d.round(2))
```

0.00 mm

0.12 \pm 0.0

N experimentell Die zurückgegebenen Werte werden in 10^{-3} angegeben.

```
[46]: def N(delta_H):
      delta_H = delta_H * 1e3
      M_max = 0.12 * 1e6

      avg = delta_H / M_max
      return round(avg*1e3, 2)
```

```
[47]: def N_err(delta_H, delta_H_err):
      # fix magnitude
      h = delta_H * 1e3
      err_h = delta_H_err * 1e3

      # constants
      M_max = 0.12 * 1e6
      err_M = 0.08 * 1e6

      err_squared = (err_h/M_max)**2 + (h*err_M/(M_max**2))**2
      return round(math.sqrt(err_squared)*1e3, 2)
```

```
[48]: def N_theo(l_L):
      R = 15 # mm
      return round(l_L / (2*math.pi*R + l_L) * 1e3, 3)
```

```
[49]: spaltbreiten = [0, 0.15, 0.25, 0.4, 1, 2]
delta_H = [
    (0,0.3), # 0 mm
    (0.17, 0.03), # 0.15 mm
    (0.29, 0.03), # 0.25 mm
    (0.44, 0.02), # 0.4 mm
    (0.93, 0.02), # 1 mm
    (1.43, 0.01) # 2mm
]

N_exp_result = [ N(h) for h, err in delta_H ]
N_exp_err = [ N_err(h, err) for h, err in delta_H ]
N_theo_result = [ N_theo(d) for d in spaltbreiten ]
```

```
[50]: df = pd.DataFrame(
    {
        '$l_L$ in [mm]': spaltbreiten,
        '$N$': N_exp_result,
        r'$\Delta N$': N_exp_err,
        r'$N_{\mathrm{theo}}$': N_theo_result
    }
)
df
```

```
[50]:
```

	l_L in [mm]	N	ΔN	N_{theo}
0	0.00	0.00	2.50	0.000
1	0.15	1.42	0.98	1.589
2	0.25	2.42	1.63	2.646
3	0.40	3.67	2.45	4.226
4	1.00	7.75	5.17	10.499
5	2.00	11.92	7.94	20.780

```
[51]: ax = sns.scatterplot(df, x='$l_L$ in [mm]', y='$N$', label=r'$N_{\mathrm{exp}}$',
    color='blue')
sns.scatterplot(df, x='$l_L$ in [mm]', y=r'$N_{\mathrm{theo}}$',
    label=r'$N_{\mathrm{theo}}$', color='red', ax=ax)
sns.mpl.pyplot.errorbar(x=df['$l_L$ in [mm]'], y=df['$N$'], yerr=df[r'$\Delta N$',
    color='blue'])

ax.figure.savefig('../media/B2.4/3.3.4_N.svg', bbox_inches='tight')
```