01_straightness

May 13, 2021

1 Determine paralleism of z-axis to spindle axis of RA-2200

Use straightness measurements of Wecan Sample 1 measured on opposite sides to separate part and machine profiles.
This is analogous to straightedge reversal as described in:

Evans, Chris J., Robert J. Hocken, and W. Tyler Estler. "Self-Calibration: Reversal, Redundancy, Error Separation, and [']Absolute Testing'." CIRP Annals - Manufacturing Technology 45, no. 2 (1996): 617–34. https://doi.org/10.1016/S0007-8506(07)60515-0.

[1]:

```
from pathlib import Path
import numpy as np
import pandas as pd
```

[2]:

```
DATA_DIR = Path(r"C:\Users\e.
 ↪howick\gits\ls_RA2200\spindle_parallesism_2021-05\data\raw")
```

[3]:

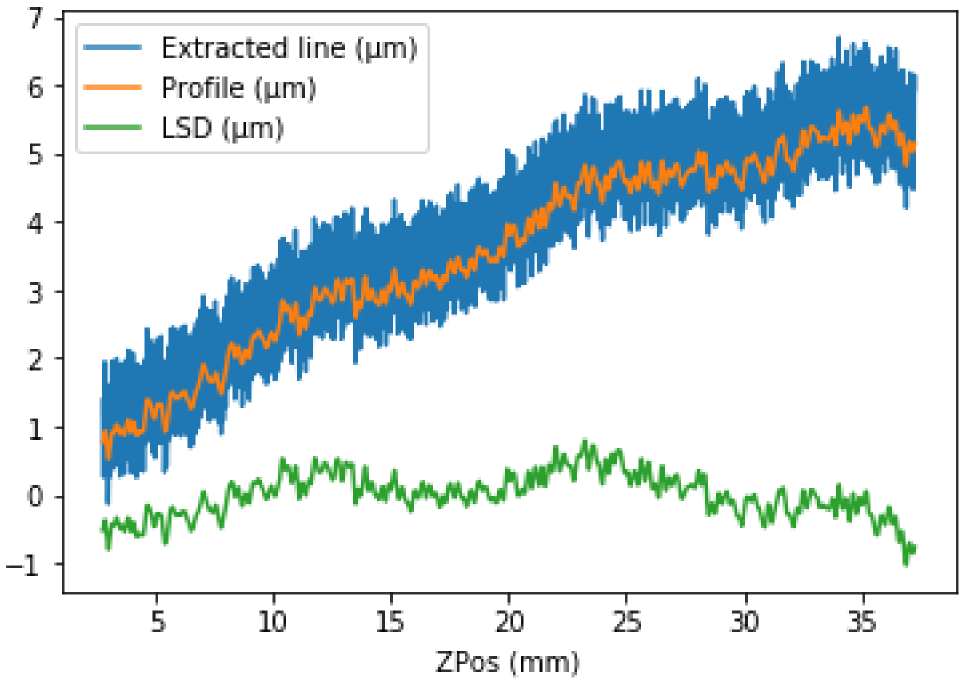
```
files = sorted(list(DATA_DIR.glob("Straight*.txt")))
files
```

[3]:

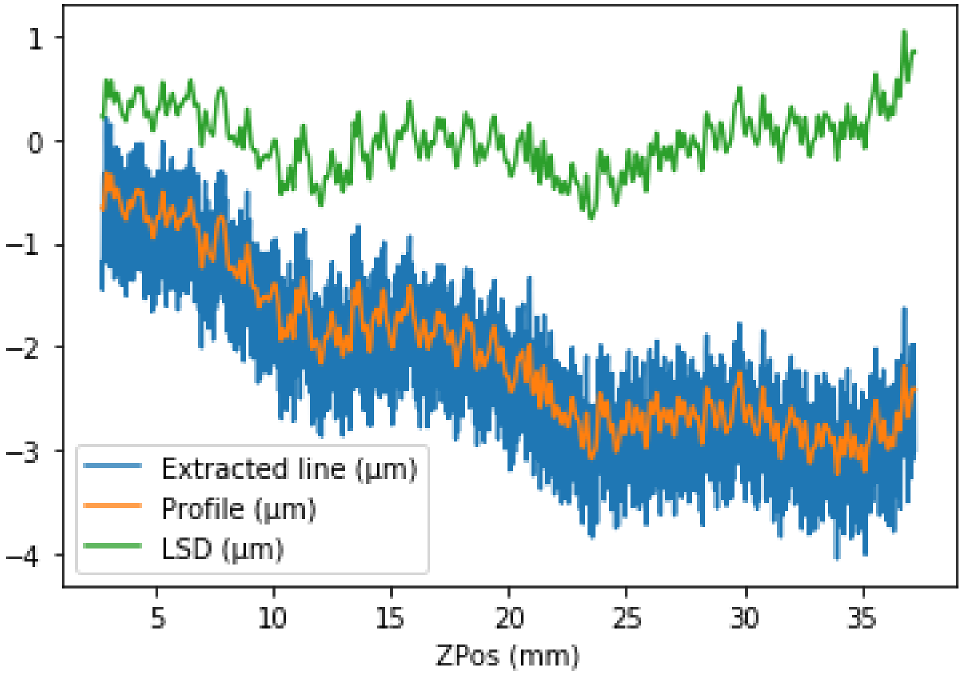
```
[WindowsPath('C:/Users/e.howick/gits/ls_RA2200/spindle_parallesism_2021-05/data/
raw/straightness_S1_opp.txt'),
 WindowsPath('C:/Users/e.howick/gits/ls_RA2200/spindle_parallesism_2021-05/data/
raw/straightness_S1_outer.txt'),
 WindowsPath('C:/Users/e.howick/gits/ls_RA2200/spindle_parallesism_2021-05/data/
raw/straightness_S2_opp_wire.txt'),
 WindowsPath('C:/Users/e.howick/gits/ls_RA2200/spindle_parallesism_2021-05/data/
raw/straightness_S2_outer_wire.txt')]
```

[4]:

```
S1_opp = pd.read_csv(files[0], skiprows=18, header=0, skipfooter=1,␣
 ↪engine='python')
S1_opp = S1_opp.drop(['Curve No.', 'Delete Flag'], axis=1)
S1_opp.plot('ZPos (mm)', ['Extracted line (µm)', 'Profile (µm)', 'LSD (µm)']);
```



```
[5]: S1_out = pd.read_csv(files[1], skiprows=18, header=0, skipfooter=1,␣
      ↪engine='python')
     S1_out = S1_out.drop(['Curve No.', 'Delete Flag'], axis=1)
     S1_out.plot('ZPos (mm)', ['Extracted line (µm)', 'Profile (µm)', 'LSD (µm)']);
```



[6]:

```
# interpolate onto same index and combine dfs
start = max(S1_opp.loc[0, 'ZPos (mm)'], S1_out.loc[0, 'ZPos (mm)'])
stop  = min(S1_opp.loc[S1_opp.index[-1] , 'ZPos (mm)'], S1_out.loc[S1_out.
 ↪index[-1] , 'ZPos (mm)'])
interval = 0.004
zpos = np.arange(start, stop, interval)
df1 = S1_opp.set_index('ZPos (mm)')
df1 = df1.reindex(df1.index | zpos).interpolate(method='index',␣
 ↪limit_direction='both').loc[zpos]
df2 = S1_out.set_index('ZPos (mm)')
df2 = df2.reindex(df2.index | zpos).interpolate(method='index',␣
 ↪limit_direction='both').loc[zpos]
S1 = pd.concat([df1, df2], axis=1)
S1.columns = [c + '_opp' for c in df1.columns] + [c + '_out' for c in df2.
 ↪columns]
S1
```

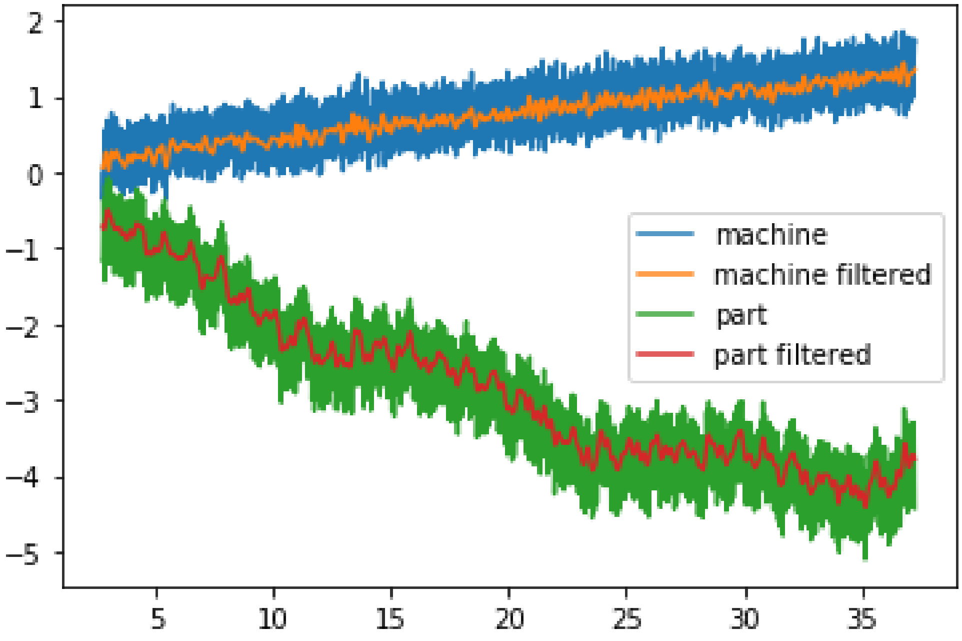
[6]:

```
         Point No._opp  Extracted line (µm)_opp  Profile (µm)_opp  \
2.7545             2.0                   1.1596            0.7722
2.7585             3.0                   0.9841            0.7757
2.7625             4.0                   0.8333            0.7792
2.7665             5.0                   0.6747            0.7829
2.7705             6.0                   0.5330            0.7870
…                …                      …               …
37.2305         8621.0                   5.3638            5.1084
37.2345         8622.0                   5.5978            5.1157
37.2385         8623.0                   5.8773            5.1225
37.2425         8624.0                   6.1113            5.1287
37.2465         8625.0                   6.1451            5.1341

         LSD (µm)_opp  Point No._out  Extracted line (µm)_out  \
2.7545        -0.5179            1.0                  -1.1817
2.7585        -0.5149            2.0                  -1.3559
2.7625        -0.5119            3.0                  -1.4521
2.7665        -0.5087            4.0                  -1.3923
2.7705        -0.5052            5.0                  -1.2090
…               …            …                      …
37.2305       -0.7877         8620.0                  -2.2672
37.2345       -0.7809         8621.0                  -2.3712
37.2385       -0.7746         8622.0                  -2.4895
37.2425       -0.7690         8623.0                  -2.6078
37.2465       -0.7642         8624.0                  -2.7183

         Profile (µm)_out  LSD (µm)_out
```

```
2.7545              -0.6546        0.2273
2.7585              -0.6623        0.2198
2.7625              -0.6687        0.2137
2.7665              -0.6737        0.2090
2.7705              -0.6773        0.2056
…                     …            …
37.2305             -2.4127        0.8457
37.2345             -2.4146        0.8441
37.2385             -2.4161        0.8428
37.2425             -2.4173        0.8419
37.2465             -2.4180        0.8415

[8624 rows x 8 columns]
```

[7]:
```
# the signs chosen to match directions given by wire taped to surface
S1['machine'] = (S1['Extracted line (µm)_out'] + S1['Extracted line (µm)_opp'])/
 ↪2.0
S1['part'] = (S1['Extracted line (µm)_out'] - S1['Extracted line (µm)_opp'])/2.0
S1['machine filtered'] = (S1['Profile (µm)_out'] + S1['Profile (µm)_opp'])/2.0
S1['part filtered'] = (S1['Profile (µm)_out'] - S1['Profile (µm)_opp'])/2.0
```

[8]:
```
S1.plot(y=['machine', 'machine filtered','part', 'part filtered']);
```



The machine profile is straight as expected and a similar magnitude to error seen when cylindrical square was measured both ways up.
Also the part was shown to have a smaller diameter at height of 35 mm than at 5 mm by cylindricity

measurements. THis is confirmed by above separation.

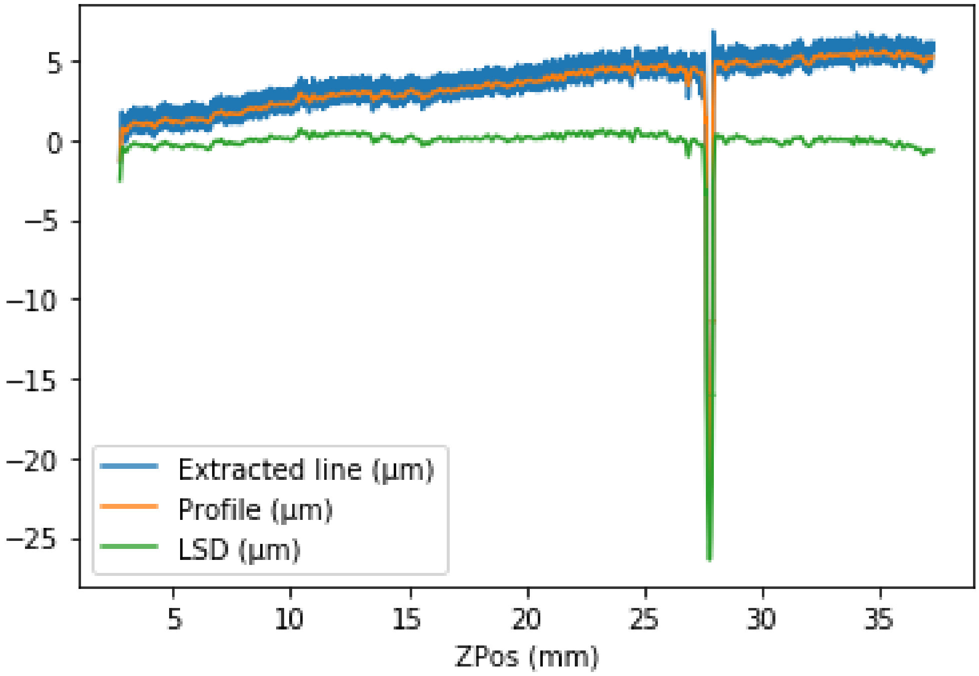
[9]:
```
d = np.polyfit(S1.index, S1['machine filtered'], 1)
d, d[0]*35
```

[9]:
```
(array([0.03231842, 0.11532339]), 1.1311447026431831)
```

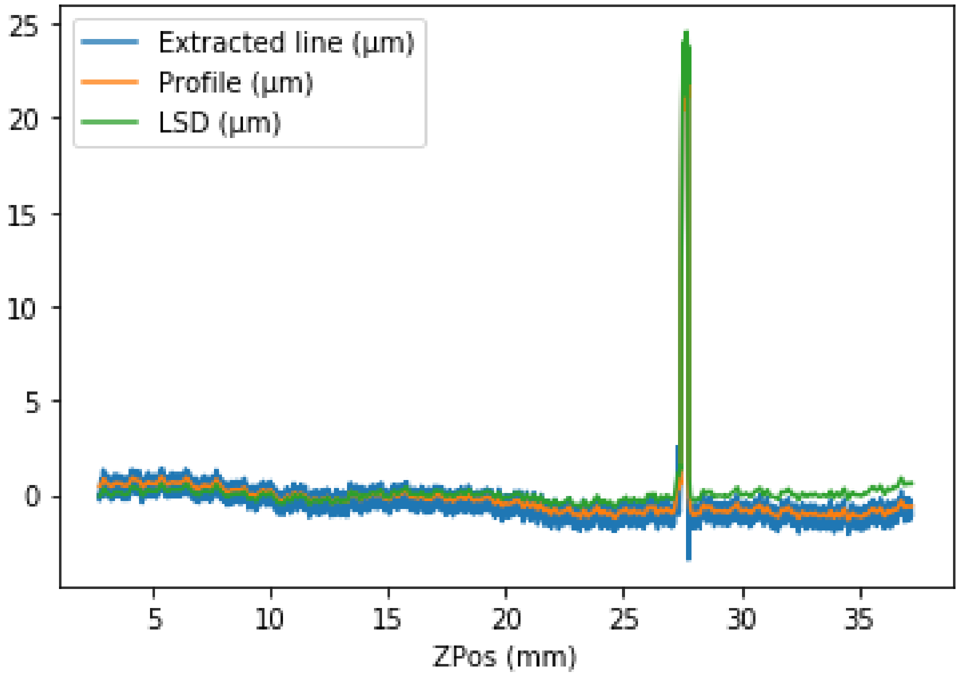
This gives 0.032 µm/mm of slope between spindle axis and z-axis. Giving a 1.13 µm error over 35 mm.

2 Repeat with wire taped to surface

[10]:
```
S1_opp = pd.read_csv(files[2], skiprows=18, header=0, skipfooter=1,␣
 ↪engine='python')
S1_opp = S1_opp.drop(['Curve No.', 'Delete Flag'], axis=1)
S1_opp.plot('ZPos (mm)', ['Extracted line (µm)', 'Profile (µm)', 'LSD (µm)']);
```



[11]:
```
S1_out = pd.read_csv(files[3], skiprows=18, header=0, skipfooter=1,␣
 ↪engine='python')
S1_out = S1_out.drop(['Curve No.', 'Delete Flag'], axis=1)
S1_out.plot('ZPos (mm)', ['Extracted line (µm)', 'Profile (µm)', 'LSD (µm)']);
```



[12]:

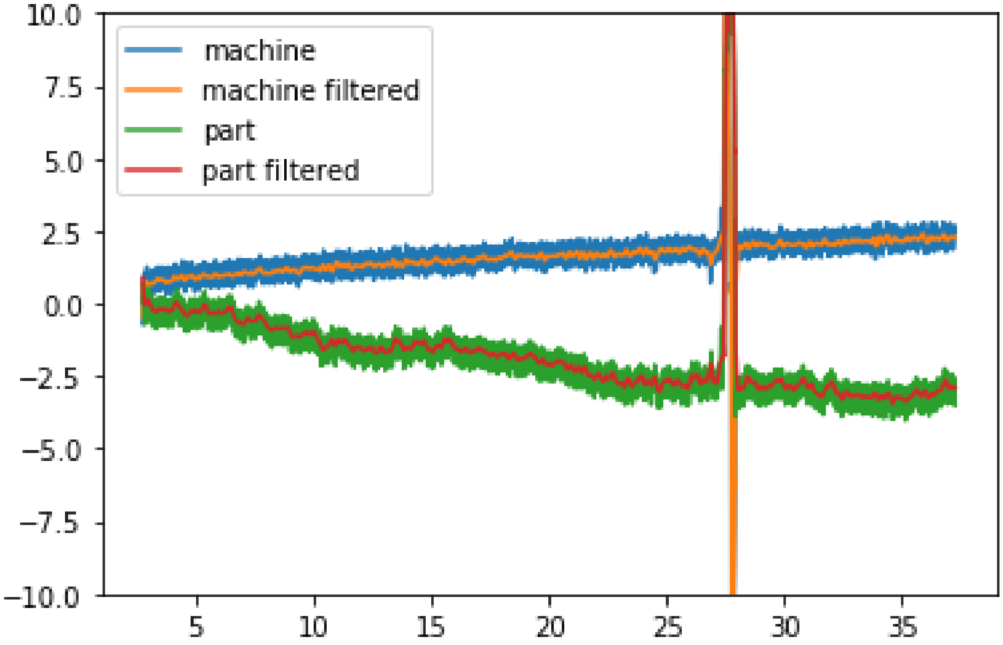
```
# interpolate onto same index and combine dfs
start = max(S1_opp.loc[0, 'ZPos (mm)'], S1_out.loc[0, 'ZPos (mm)'])
stop  = min(S1_opp.loc[S1_opp.index[-1] , 'ZPos (mm)'], S1_out.loc[S1_out.
 ↪index[-1] , 'ZPos (mm)'])
interval = 0.004
zpos = np.arange(start, stop, interval)
df1 = S1_opp.set_index('ZPos (mm)')
df1 = df1.reindex(df1.index | zpos).interpolate(method='index',␣
 ↪limit_direction='both').loc[zpos]
df2 = S1_out.set_index('ZPos (mm)')
df2 = df2.reindex(df2.index | zpos).interpolate(method='index',␣
 ↪limit_direction='both').loc[zpos]
S1 = pd.concat([df1, df2], axis=1)
S1.columns = [c + '_opp' for c in df1.columns] + [c + '_out' for c in df2.
 ↪columns]
```

[13]:

```
S1['machine'] = (S1['Extracted line (µm)_out'] + S1['Extracted line (µm)_opp'])/
 ↪2.0
S1['part'] = (S1['Extracted line (µm)_out'] - S1['Extracted line (µm)_opp'])/2.0
S1['machine filtered'] = (S1['Profile (µm)_out'] + S1['Profile (µm)_opp'])/2.0
S1['part filtered'] = (S1['Profile (µm)_out'] - S1['Profile (µm)_opp'])/2.0
```

[14]:

```
S1.plot(y=['machine', 'machine filtered','part', 'part filtered'], ylim=(-10,␣
 ↪10));
```



The wire is not entirely removed from both profiles. But signs are shown to be correct.