```
In [1]:
# Importing the required libraries
import numpy as np
import pandas as pd
import os
import time
from datetime import timedelta
from sklearn.model_selection import train_test_split, cross_val_score
from sklearn.metrics import classification_report
from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import RandomizedSearchCV
from sklearn.metrics import confusion_matrix , classification_report, f1_score,\
from sklearn.model_selection import RandomizedSearchCV, train_test_split, f1_score

from sklearn.preprocessing import LabelEncoder
from sklearn.model_selection import train_test_split, cross_val_score
from sklearn.metrics import classification_report
from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import RandomizedSearchCV
from sklearn.metrics import confusion_matrix , classification_report, f1_score,\
from sklearn.model_selection import RandomizedSearchCV, train_test_split, f1_score

%%%% #

In [2]:
# connection connection
conn = pyodbc.connect('Driver={SQL Server};'
                      'Server=LAPTOP-SBNFTQ6S;'
                      'Database=DB_CTRL_TUNNEL;'
                      'Trusted_Connection=yes;')

cursor = conn.cursor()

In [3]:
read1=pd.read_sql_query('SELECT * FROM dbo.ReadCase001', conn)
read2=pd.read_sql_query('SELECT * FROM dbo.ReadCase002', conn)
read3=pd.read_sql_query('SELECT * FROM dbo.ReadCase003', conn)
read4=pd.read_sql_query('SELECT * FROM dbo.ReadCase004', conn)
read5=pd.read_sql_query('SELECT * FROM dbo.ReadCase005', conn)
read6=pd.read_sql_query('SELECT * FROM dbo.ReadCase006', conn)

In [4]:
read1['Condition'] = 1
read2['Condition'] = 2
read3['Condition'] = 3
read4['Condition'] = 4
read5['Condition'] = 5
read6['Condition'] = 6

In [5]:
df = pd.concat([read1,read2,
                read3,read4,
                read5,read6,
                ], ignore_index=True)

In [6]:
df.head()

Out[6]:
```

	Timestamp	pCut Motor Torque	pCut CTRL Position controller Lag error	pCut CTRL Position controller Actual position	pCut CTRL Position controller Actual speed	pCut CTRL Position controller Actual torque	pSvolFilm CTRL Position controller Actual position	pSvolFilm CTRL Position controller Actual speed	pSvolFilm CTRL Position controller Lag error	Condition
0	0.48	0.0	0.001562	49449.0	0.000000	0.000000	111263	0.000000	0.000000	1
1	0.58	-0.008057	0.001562	49449.0	-0.146728	-0.732910	111263	-2.036249	0.026001	1
2	0.68	0.115161	0.001562	49449.0	0.146455	0.732910	111263	2.036249	0.026001	1
3	0.78	-0.173071	0.001562	49449.0	-0.732910	-0.732910	111263	-2.036249	0.026001	1
4	0.88	0.230713	0.001562	49449.0	0.732910	0.732910	111263	2.036249	0.026001	1

```
In [7]:
df.info()

<class 'pandas.core.frame.DataFrame'>
RangeIndex: 18720 entries, 0 to 18719
Data columns (total 10 columns):
 #   Column                                  Non-Null Count  Dtype
---  ------                                  --------------  -----
 0   Timestamp                               18720 non-null  float64
 1   pCut Motor Torque                       18720 non-null  float64
 2   pCut CTRL Position controller Lag error 18720 non-null  float64
 3   pCut CTRL Position controller Actual position 18720 non-null  float64
 4   pCut CTRL Position controller Actual speed 18720 non-null  float64
 5   pCut CTRL Position controller Actual torque 18720 non-null  float64
 6   pSvolFilm CTRL Position controller Actual position 18720 non-null  float64
 7   pSvolFilm CTRL Position controller Actual speed 18720 non-null  float64
 8   pSvolFilm CTRL Position controller Lag error 18720 non-null  float64
 9   Condition                               18720 non-null  int64
dtypes: float64(9), int64(1)
memory usage: 1.4 MB

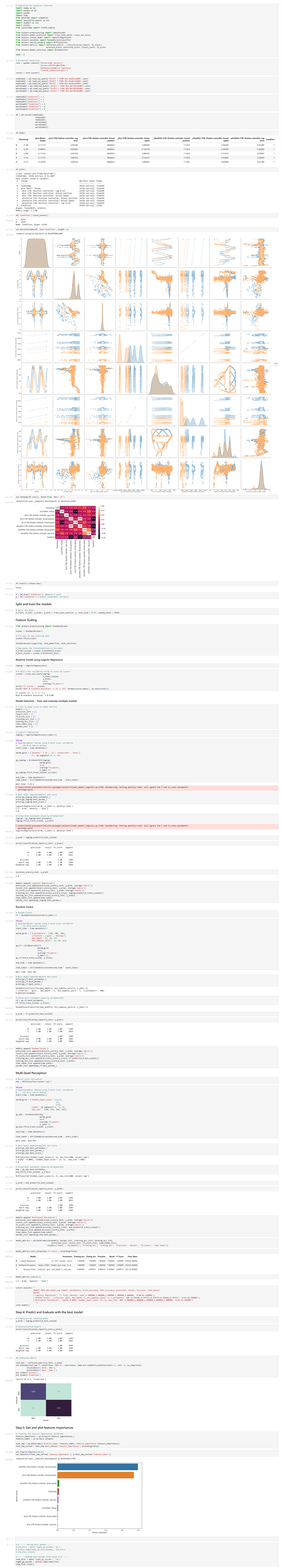
In [8]:
df['Condition'].value_counts()

Out[8]:
1    3120
2    3120
3    3120
4    3120
5    3120
6    3120
Name: Condition, dtype: int64

In [9]:
!jupyter nbextension enable --py --sys-prefix ipyscales

Enabling notebook extension ipyscales/extension...
      - Validating: OK

In [10]:
import ipyvolume.pylab as p3
import ipyvolume as ipv
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
sns.set(color_codes=True)
%matplotlib inline
```



```
In [11]:
sns.heatmap(df.corr(), annot=True, fmt='.2')

Out[11]:
<matplotlib.axes._subplots.AxesSubplot at 0x1f4c2c3c508>
```



```
In [12]:
df.shape

Out[12]:
(18720, 10)

In [13]:
df.dtypes

Out[13]:
Timestamp                                 float64
pCut Motor Torque                         float64
pCut CTRL Position controller Lag error   float64
pCut CTRL Position controller Actual position  float64
pCut CTRL Position controller Actual speed  float64
pCut CTRL Position controller Actual torque  float64
pSvolFilm CTRL Position controller Actual position  float64
pSvolFilm CTRL Position controller Actual speed  float64
pSvolFilm CTRL Position controller Lag error  float64
Condition                                   int64
dtype: object

In [14]:
df.isnull().sum()

Out[14]:
Timestamp                                 0
pCut Motor Torque                         0
pCut CTRL Position controller Lag error   0
pCut CTRL Position controller Actual position  0
pCut CTRL Position controller Actual speed  0
pCut CTRL Position controller Actual torque  0
pSvolFilm CTRL Position controller Actual position  0
pSvolFilm CTRL Position controller Actual speed  0
pSvolFilm CTRL Position controller Lag error  0
Condition                                   0
dtype: int64

In [15]:
df.isnull().values.any()

Out[15]:
False

In [16]:
X = df.drop('Condition', axis=1) # input
y = df['Condition'] # output (Dependent Variable)
```

Split and train the models

```
In [17]:
# Split the data
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size = 0.25, random_state = 1000)
```

Feature Scaling

```
In [18]:
from sklearn.preprocessing import StandardScaler

scaler = StandardScaler()

# Fit only to the training data
scaler.fit(X_train)

StandardScaler(copy=True, with_mean=True, with_std=True)

# Now apply the transformations to the data:
X_train_scaled = scaler.transform(X_train)
X_test_scaled = scaler.transform(X_test)
```

Baseline model using Logistic Regression

```
In [19]:
logreg = LogisticRegression()

# A final cross validation using 15 score as score'
scores = cross_val_score(logreg,
                         X_train_scaled,
                         y_train,
                         cv=5,
                         scoring='f1_macro')

print("F1 scores: ", scores)
print("Mean & standard deviation: {:.2} (+/- {:.2f})".format(scores.mean(), sp.std(scores))

F1 scores: [1. 1. 1. 1. 1.]
Mean & standard deviation: 1.0 (+/- 0.00
```

Model Selection - Train and evaluate multiple models

```
In [20]:
# Since my base level of model metrics
models = []
accuracy_list = []
recall_list = []
f1_score_list = []
training_acc_list = []
testing_acc_list = []
time_taken_list = []
params_list = []

# Logistic Regression
logreg = LogisticRegression(n_jobs=-1)

%%time
# Hyperparameter tuning using 4 fold cross validation
start_time = time.monotonic()
start_time = time.monotonic()

param_grid = {'penalty' : ['l2', 'l1', 'elasticnet', 'none'],
              'C' : np.logspace(-3,3,7),
              }

gs_logreg = GridSearchCV(logreg,
                         param_grid,
                         cv=4,
                         n_jobs=-1,
                         scoring='f1_macro',
                         verbose=1)

gs_logreg.fit(X_train_scaled, y_train)

end_time = time.monotonic()
print(timedelta(seconds=end_time - start_time))

Wall time: 3.19 s
C:\Users\Sathy\anaconda3\lib\site-packages\sklearn\linear_model\_logistic.py:1330: UserWarning: Setting penalty='none' will ignore the C and l1_ratio parameters
  warnings.warn(
C:\Users\Sathy\anaconda3\lib\site-packages\sklearn\linear_model\_logistic.py:1330: UserWarning: Setting penalty='none' will ignore the C and l1_ratio parameters
  warnings.warn(

In [21]:
# Best model hyperparameters and score
print(gs_logreg.best_estimator_)
print(gs_logreg.best_params_)
print(gs_logreg.best_score_)

LogisticRegression(C=0.001, n_jobs=-1, penalty='none')
{'C': 0.001, 'penalty': 'none'}
1.0

In [22]:
# Using best estimator found by GridSearchCV
logreg = gs_logreg.best_estimator_
logreg.fit(X_train_scaled, y_train)

LogisticRegression(C=0.001, n_jobs=-1, penalty='none')

In [23]:
y_pred = logreg.predict(X_test_scaled)

In [24]:
print(classification_report(y_test, y_pred))

              precision    recall  f1-score   support

           1       1.00      1.00      1.00       780
           2       1.00      1.00      1.00       780
           3       1.00      1.00      1.00       780
           4       1.00      1.00      1.00       780
           5       1.00      1.00      1.00       780
           6       1.00      1.00      1.00       780

    accuracy                           1.00      4680
   macro avg       1.00      1.00      1.00      4680
weighted avg       1.00      1.00      1.00      4680

In [25]:
accuracy_score(y_test, y_pred)

Out[25]:
1.0

In [26]:
models.append('Logistic Regression')
precision_list.append(precision_score(y_test, y_pred, average='macro'))
recall_list.append(recall_score(y_test, y_pred, average='macro'))
f1_score_list.append(f1_score(y_test, y_pred, average='macro'))
training_acc_list.append(accuracy_score(y_train, logreg.predict(X_train_scaled)))
testing_acc_list.append(accuracy_score(y_test, y_pred))
time_taken_list.append(time_taken)
params_list.append(gs_logreg.best_params_)
```

Random Forest

```
In [27]:
# Random Forest
rf = RandomForestClassifier(n_jobs=-1)

%%time
# Hyperparameter tuning using 4 fold cross validation
start_time = time.monotonic()
start_time = time.monotonic()

param_grid = {'n_estimators': [100, 200, 300],
              'criterion' : ['gini', 'entropy'],
              'max_depth' : [4, 5, 6, 7, 8],
              'min_samples_split': [5, 10, 15]
              }

gs_rf = GridSearchCV(rf,
                     param_grid,
                     cv=4,
                     n_jobs=-1,
                     scoring='f1_macro',
                     verbose=1)

gs_rf.fit(X_train_scaled, y_train)

end_time = time.monotonic()

time_taken = str(timedelta(seconds=end_time - start_time))

Wall time: 6min 49s

In [28]:
# Best model hyperparameters and score
print(gs_rf.best_estimator_)
print(gs_rf.best_params_)
print(gs_rf.best_score_)

RandomForestClassifier(max_depth=8, min_samples_split=5, n_jobs=-1)
{'criterion': 'gini', 'max_depth': 8, 'min_samples_split': 5, 'n_estimators': 100}
0.9999999999999999

In [29]:
# Using best estimator found by GridSearchCV
rf = gs_rf.best_estimator_
rf.fit(X_train_scaled, y_train)

RandomForestClassifier(max_depth=8, min_samples_split=5, n_jobs=-1)

In [30]:
y_pred = rf.predict(X_test_scaled)

In [31]:
print(classification_report(y_test, y_pred))

              precision    recall  f1-score   support

           1       1.00      1.00      1.00       780
           2       1.00      1.00      1.00       780
           3       1.00      1.00      1.00       780
           4       1.00      1.00      1.00       780
           5       1.00      1.00      1.00       780
           6       1.00      1.00      1.00       780

    accuracy                           1.00      4680
   macro avg       1.00      1.00      1.00      4680
weighted avg       1.00      1.00      1.00      4680

In [32]:
models.append('Random Forest')
precision_list.append(precision_score(y_test, y_pred, average='macro'))
recall_list.append(recall_score(y_test, y_pred, average='macro'))
f1_score_list.append(f1_score(y_test, y_pred, average='macro'))
training_acc_list.append(accuracy_score(y_train, rf.predict(X_train_scaled)))
testing_acc_list.append(accuracy_score(y_test, y_pred))
time_taken_list.append(time_taken)
params_list.append(gs_rf.best_params_)
```

Multi-level Perceptron

```
In [33]:
# Multi-level Perceptron
mlp = MLPClassifier(verbose='mlp')

%%time
# Hyperparameter tuning using 4 fold cross validation
start_time = time.monotonic()
start_time = time.monotonic()

param_grid = {'hidden_layer_sizes': [(3,3),
                                     (4),
                                     (5,5),
                                     ],
              'alpha' : np.logspace(-4, 2, 6),
              'max_iter': [500, 750, 1000, 1500],
              }

gs_mlp = GridSearchCV(mlp,
                      param_grid,
                      cv=4,
                      n_jobs=-1,
                      scoring='f1_macro',
                      verbose=1)

gs_mlp.fit(X_train_scaled, y_train)

end_time = time.monotonic()

time_taken = str(timedelta(seconds=end_time - start_time))

Wall time: 6min 49s

In [34]:
# Best model hyperparameters and score
print(gs_mlp.best_estimator_)
print(gs_mlp.best_params_)
print(gs_mlp.best_score_)

MLPClassifier(alpha=0.0001, hidden_layer_sizes=(5, 5), max_iter=1000, verbose='mlp')
{'alpha': 0.0001, 'hidden_layer_sizes': (5, 5), 'max_iter': 1000}
1.0

In [35]:
# Using best estimator found by GridSearchCV
mlp = gs_mlp.best_estimator_
mlp.fit(X_train_scaled, y_train)

MLPClassifier(hidden_layer_sizes=(5, 5), max_iter=1000, verbose='mlp')

Iteration 1, loss = 1.79178825
Iteration 2, loss = 1.78911284
Iteration 3, loss = 1.78650139
Iteration 4, loss = 1.78394966
Iteration 5, loss = 1.78145350
Iteration 6, loss = 1.77900911
Iteration 7, loss = 1.77661290
Iteration 8, loss = 1.77426151
Iteration 9, loss = 1.77195176
Iteration 10, loss = 1.76968060
Iteration 11, loss = 1.76744514
Iteration 12, loss = 1.76524262
Iteration 13, loss = 1.76307040
Iteration 14, loss = 1.76092600
Iteration 15, loss = 1.75880705
Iteration 16, loss = 1.75671130
Iteration 17, loss = 1.75463659
Iteration 18, loss = 1.75258086
Iteration 19, loss = 1.75054211
Iteration 20, loss = 1.74851844
Iteration 21, loss = 1.74650802
Iteration 22, loss = 1.74450911
Iteration 23, loss = 1.74252004
Iteration 24, loss = 1.74053918
Iteration 25, loss = 1.73856496
Iteration 26, loss = 1.73659587
Iteration 27, loss = 1.73463044
Iteration 28, loss = 1.73266726
Iteration 29, loss = 1.73070497
Iteration 30, loss = 1.72874224
Iteration 31, loss = 1.72677779
Iteration 32, loss = 1.72481037
Iteration 33, loss = 1.72283880
Iteration 34, loss = 1.72086194
Iteration 35, loss = 1.71887870
Iteration 36, loss = 1.71688806
Iteration 37, loss = 1.71488904
Iteration 38, loss = 1.71288073
Iteration 39, loss = 1.71086227
Iteration 40, loss = 1.70883286
Iteration 41, loss = 1.70679176
Iteration 42, loss = 1.70473829
Iteration 43, loss = 1.70267183
Iteration 44, loss = 1.70059183
Iteration 45, loss = 1.69849781
Iteration 46, loss = 1.69638935
Iteration 47, loss = 1.69426611
Iteration 48, loss = 1.69212781
Iteration 49, loss = 1.68997424
Iteration 50, loss = 1.68780525
Iteration 51, loss = 1.68562073
Iteration 52, loss = 1.68342064
Iteration 53, loss = 1.68120500
Iteration 54, loss = 1.67897389
Iteration 55, loss = 1.67672746
Iteration 56, loss = 1.67446592
Iteration 57, loss = 1.67218955
Iteration 58, loss = 1.66989870
Iteration 59, loss = 1.66759378
Iteration 60, loss = 1.66527525
Iteration 61, loss = 1.66294363
Iteration 62, loss = 1.66059950
Iteration 63, loss = 1.65824350
Iteration 64, loss = 1.65587630
Iteration 65, loss = 1.65349859
Iteration 66, loss = 1.65111112
Iteration 67, loss = 1.64871468
Iteration 68, loss = 1.64631008
Iteration 69, loss = 1.64389819
Iteration 70, loss = 1.64147990
Iteration 71, loss = 1.63905611
Iteration 72, loss = 1.63662776
Iteration 73, loss = 1.63419581
Iteration 74, loss = 1.63176125
Iteration 75, loss = 1.62932509
Iteration 76, loss = 1.62688835
Iteration 77, loss = 1.62445206
Iteration 78, loss = 1.62201726
Iteration 79, loss = 1.61958499
Iteration 80, loss = 1.61715630
Iteration 81, loss = 1.61473224
Iteration 82, loss = 1.61231385
Iteration 83, loss = 1.60990216
Iteration 84, loss = 1.60749818
Iteration 85, loss = 1.60510289
Iteration 86, loss = 1.60271724
Iteration 87, loss = 1.60034212
Iteration 88, loss = 1.59797837
Iteration 89, loss = 1.59562677
Iteration 90, loss = 1.59328802
Iteration 91, loss = 1.59096273
Iteration 92, loss = 1.58865141
Iteration 93, loss = 1.58635446
Iteration 94, loss = 1.58407216
Iteration 95, loss = 1.58180464
Iteration 96, loss = 1.57955187
Iteration 97, loss = 1.57731369
Iteration 98, loss = 1.57508977
Iteration 99, loss = 1.57287966
Iteration 100, loss = 1.57068276
Iteration 101, loss = 1.56849835
Iteration 102, loss = 1.56632559
Iteration 103, loss = 1.56416353
Iteration 104, loss = 1.56201111
Iteration 105, loss = 1.55986715
Iteration 106, loss = 1.55773040
Iteration 107, loss = 1.55559955
Iteration 108, loss = 1.55347322
Iteration 109, loss = 1.55134999
Iteration 110, loss = 1.54922844
Iteration 111, loss = 1.54710713
Iteration 112, loss = 1.54498464
Iteration 113, loss = 1.54285957
Iteration 114, loss = 1.54073057
Iteration 115, loss = 1.53859636
Iteration 116, loss = 1.53645574
Iteration 117, loss = 1.53430763
Iteration 118, loss = 1.53215109
Iteration 119, loss = 1.52998532
Iteration 120, loss = 1.52780971
Iteration 121, loss = 1.52562387
Iteration 122, loss = 1.52342766
Iteration 123, loss = 1.52122120
Iteration 124, loss = 1.51900492
Iteration 125, loss = 1.51677960
Iteration 126, loss = 1.51454636
Iteration 127, loss = 1.51230665
Iteration 128, loss = 1.51006222
Iteration 129, loss = 1.50781503
Iteration 130, loss = 1.50556722
Iteration 131, loss = 1.50332102
Iteration 132, loss = 1.50107866
Iteration 133, loss = 1.49884233
Iteration 134, loss = 1.49661410
Iteration 135, loss = 1.49439588
Iteration 136, loss = 1.49218940
Iteration 137, loss = 1.48999618
Iteration 138, loss = 1.48781747
Iteration 139, loss = 1.48565424
Iteration 140, loss = 1.48350719
Iteration 141, loss = 1.48137669
Iteration 142, loss = 1.47926276
Iteration 143, loss = 1.47716503
Iteration 144, loss = 1.47508277
Iteration 145, loss = 1.47301488
Iteration 146, loss = 1.47095997
Iteration 147, loss = 1.46891643
Iteration 148, loss = 1.46688253
Iteration 149, loss = 1.46485650
Iteration 150, loss = 1.46283660
Iteration 151, loss = 1.46082115
Iteration 152, loss = 1.45880859
Iteration 153, loss = 1.45679750
Iteration 154, loss = 1.45478664
Iteration 155, loss = 1.45277501
Iteration 156, loss = 1.45076181
Iteration 157, loss = 1.44874650
Iteration 158, loss = 1.44672875
Iteration 159, loss = 1.44470844
Iteration 160, loss = 1.44268567
Iteration 161, loss = 1.44066071
Iteration 162, loss = 1.43863405
Iteration 163, loss = 1.43660630
Iteration 164, loss = 1.43457814
Iteration 165, loss = 1.43255031
Iteration 166, loss = 1.43052358
Iteration 167, loss = 1.42849870
Iteration 168, loss = 1.42647641
Iteration 169, loss = 1.42445741
Iteration 170, loss = 1.42244233
Iteration 171, loss = 1.42043172
Iteration 172, loss = 1.41842604
Iteration 173, loss = 1.41642567
Iteration 174, loss = 1.41443090
Iteration 175, loss = 1.41244193
Iteration 176, loss = 1.41045886
Iteration 177, loss = 1.40848172
Iteration 178, loss = 1.40651045
Iteration 179, loss = 1.40454490
Iteration 180, loss = 1.40258484
Iteration 181, loss = 1.40062997
Iteration 182, loss = 1.39867993
Iteration 183, loss = 1.39673432
Iteration 184, loss = 1.39479273
Iteration 185, loss = 1.39285475
Iteration 186, loss = 1.39091999
Iteration 187, loss = 1.38898809
Iteration 188, loss = 1.38705875
Iteration 189, loss = 1.38513172
Iteration 190, loss = 1.38320681
Iteration 191, loss = 1.38128387
Iteration 192, loss = 1.37936284
Iteration 193, loss = 1.37744374
Iteration 194, loss = 1.37552665
Iteration 195, loss = 1.37361170
Iteration 196, loss = 1.37169904
Iteration 197, loss = 1.36978885
Iteration 198, loss = 1.36788130
Iteration 199, loss = 1.36597654
Iteration 200, loss = 1.36407468
Iteration 201, loss = 1.36217577
Iteration 202, loss = 1.36027980
Iteration 203, loss = 1.35838670
Iteration 204, loss = 1.35649636
Iteration 205, loss = 1.35460864
Iteration 206, loss = 1.35272337
Iteration 207, loss = 1.35084045
Iteration 208, loss = 1.34895980
Iteration 209, loss = 1.34708139
Iteration 210, loss = 1.34520525
Iteration 211, loss = 1.34333141
Iteration 212, loss = 1.34145990
Iteration 213, loss = 1.33959073
Iteration 214, loss = 1.33772389
Iteration 215, loss = 1.33585936
Iteration 216, loss = 1.33399710
Iteration 217, loss = 1.33213707
Iteration 218, loss = 1.33027923
Iteration 219, loss = 1.32842354
Iteration 220, loss = 1.32656997
Iteration 221, loss = 1.32471850
Iteration 222, loss = 1.32286913
Iteration 223, loss = 1.32102187
Iteration 224, loss = 1.31917674
Iteration 225, loss = 1.31733376
Iteration 226, loss = 1.31549295
Iteration 227, loss = 1.31365433
Iteration 228, loss = 1.31181791
Iteration 229, loss = 1.30998370
Iteration 230, loss = 1.30815170
Iteration 231, loss = 1.30632191
Iteration 232, loss = 1.30449432
Iteration 233, loss = 1.30266892
Iteration 234, loss = 1.30084570
Iteration 235, loss = 1.29902464
Iteration 236, loss = 1.29720572
Iteration 237, loss = 1.29538892
Iteration 238, loss = 1.29357421
Iteration 239, loss = 1.29176156
Iteration 240, loss = 1.28995094
Iteration 241, loss = 1.28814232
Iteration 242, loss = 1.28633566
Iteration 243, loss = 1.28453093
Iteration 244, loss = 1.28272809
Iteration 245, loss = 1.28092710
Iteration 246, loss = 1.27912792
Iteration 247, loss = 1.27733052
Iteration 248, loss = 1.27553485
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Iteration 250, loss = 1.27194857
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