Summary of revision of the Thesis (of 12PH90J05)

We express our sincere gratitude to all the Examiners for providing useful comments and suggestions on the Thesis (of 12PH90J05) entitled **"Study of Vortex Dynamics in $Bi_2Sr_2Ca_{1-x}Er_xCu_2O_{8+\delta}(0 \leq x \leq 0.3)$ and Optimally Doped $Ba_{0.54}K_{0.46}Fe_2As_2$ Superconductors"**. We have included all the points in the final version of Thesis which are pointed out by the Examiners. The summary of revision of the thesis is the following.

Response to the report of Foreign Examiner

Comment #1

It is mentioned in Chapters 3 and 5 that the activation energy follows a power law of magnetic field, but no power law formula is indicated. The power laws should be indicated explicitly, particularly in relation to Figs. 3.8 and 5.7.

Response #1

We would like to thank the Examiner for giving such nice suggestions. In Chapter 3, there is a discussion regarding the dependence of pinning potential (U) with magnetic field (H) in $Bi_2Sr_2Ca_{1-x}Er_xCu_2O_{8+\delta}$ ($x = 0.0, 0.1, 0.3$) polycrystalline samples. Here U follows power law dependence with magnetic field: $U \propto H^{-\alpha}$. In Fig. 3.8, we have obtained $\alpha = 0.6$ for $x = 0.0$, $\alpha = 0.5$ for $x = 0.1$ and $\alpha = 0.3$ for $x = 0.3$ samples, respectively in the range $H > 10\ kOe$. We have written the power law formula in the text of Chapter 3 and also in the caption of Fig. 3.8 explicitly in the final version of thesis as per suggestion.

In Chapter 5, there is a similar discussion regarding dependence of pinning potential (U) with magnetic field (H) in two different orientations ($H||c$-axis and $H||ab$ planes) of magnetic field in single crystal $Ba_{0.54}K_{0.46}Fe_2As_2$ sample. In this case also U follows power law dependence with magnetic field: $U \propto H^{-\alpha}$ but dependence is very weak below 40 kOe. We have obtained $\alpha = 0.01$for $H||c$-axis and $\alpha = 0.02$ for $H||ab$-planes when $H < 40\ kOe$. When magnetic field is greater than 40 kOe, pinning potential strongly depends on magnetic field in $H||c$-axis orientation. We have obtained $\alpha = 0.7$ for $H||c$-axis and $\alpha = 0.17$ for $H||ab$-planes when $H > 40\ kOe$. We have written the power law formula clearly in the text of Chapter 5 and also in the caption of Fig. 5.7 in the final version of thesis as per suggestion.

Comment#2

The statement that phase coherence is pronounced near Tc as a consequence of small phase stiffness in Chapter 6 is not correct. I would suggest to modify it to, e.g. phase coherence must be pronounced to achieve the high Tc and to overcome the small phase stiffness.

Response#2

We would like to thank the Examiner for giving such nice suggestions. We have modified the text in Chapter 6 as per suggestion.

Comment#3

References to the previous works which the present thesis is based on has to be made more clearly. The previous works mean particularly Refs. 62, 94, 125, and 162. It should be clearly written which results of the present thesis are new and which results are just confirmation of the previous works.

Response#3

We would like to thank the Examiner for nice suggestions. We have now clearly mentioned the references of the previous work on which present thesis is based on. We have elaborately described the previous works in the **Chapter 1** (Introduction and Basic study) and other Chapters with the explanation of the results of the present study. Main findings of the thesis are described below.

(a) Ref. 94 discusses about the effect of Ce substitution in $Bi_2Sr_2CaCu_2O_{8+\delta}$ systems on pinning potential and vortex behavior. On the other hand **Chapter 3** of the present thesis discusses about the effect of Er substitution in $Bi_2Sr_2CaCu_2O_{8+\delta}$ system on pinning potential and its dependence on magnetic field using thermally activated flux flow model (**Publication #1:** *Effect of Erbium substitution on temperature and field dependence of thermally activated flux flow resistance in Bi-2212 superconductor, D. Paladhi, P. Mandal, R. C. Sahoo, S. K. Giri and T. K. Nath, Physica B: Condensed Matter,* ***502****, 113-118 (2016).)*

(b) We have shown some new interesting results in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) polycrystalline system in the present thesis (**Chapter 4**) that nonlinear ac magnetic susceptibility suddenly increases under high magnetic field. Destruction of coherence or unusual vortex motion through the grain boundary may be possible reason for this **new unusual vortex dynamics** in Bi-2212 system (**Publication #5**: *Investigation of vortex dynamics in Bi-2212 superconductor using third harmonic ac magnetic susceptibility superposing high dc magnetic field, D. Paladhi, R. C. Sahoo, and T. K. Nath, Journal of Applied Physics and Nanotechnology,* ***1****, 001 (2018))*

(c) Ref. 125 describes about vortex dynamics and estimation of pinning potential from magnetization measurements of $Ba_{1-x}K_xFe_2As_2$ $(x = 0.28)$ underdoped single crystal $(T_c = 32.7\ K)$. In the present thesis (**Chapter 5**), pinning potential has been estimated using thermally activated flux flow (TAFF) model of optimal doped $Ba_{0.54}K_{0.46}Fe_2As_2$ single crystal with transition temperature $38.5\ K$ (**Publication #4:**

*Current-voltage characteristics near second magnetization peak and vortex dynamics of superconducting $Ba_{0.54}K_{0.46}Fe_2As_2$ single crystal, D. Paladhi, R. C. Sahoo, and T. K. Nath, Physica B: Condensed Matter, **550**, 244-249 (2018)*).

(d) In the present thesis, we have clearly shown anisotropic phase correlation persists above T_c in $Ba_{0.54}K_{0.46}Fe_2As_2$ single crystal and it is more prominent in the orientation of H||ab-planes. Apparent transition temperature (T_a) that represents the onset of phase coherence behaves differently in two main crystallographic directions: $dT_a(H)/dH > 0$ for H||ab-planes and $dT_a(H)/dH < 0$ for H||c-axis. We have suggested that multiband nature may be the possible reasons for this anomalous behavior of $T_a(H)$ in 122 type hole doped superconductor. This kind of behavior is interesting and new in this system which is described in **Chapter 6** (**Publication #3:** *Evidence of anisotropic phase correlations above Tc in single crystalline $Ba_{0.54}K_{0.46}Fe_2As_2$, D. Paladhi, R. C. Sahoo, and T. K. Nath, Physica B: Condensed Matter, **512**, 54-57 (2017)*.).

(e) Ref. 62 discusses about the second peak effect, field dependent critical current density using Bean's model, determination of irreversibility line from magnetic measurements and vortex phase diagram of $Ba_{0.6}K_{0.4}Fe_2As_2$ single crystal ($T_c = 36.2\ K$). Ref. 162 has shown vortex melting transition using specific heat, magnetization and thermal expansion measurement of $Ba_{0.5}K_{0.5}Fe_2As_2(T_c = 34.4\ K)$. On the other hand in the present thesis (**Chapter 7**), we have taken **optimal doped $Ba_{0.54}K_{0.46}Fe_2As_2$ single crystal with slightly higher transition temperature ($T_c = 38.5\ K$) which is maximum in this system.** We have shown second peak effect, field dependent critical current density using Bean's model and vortex phase diagram. **In addition to this, we have shown irreversibility line and vortex dynamics from ac susceptibility measurement.** From fundamental and higher harmonic susceptibility measurements, we have observed that irreversibility temperature (T_{irr}) strongly depends on frequency and this frequency dependence can be explained in the framework of vortex-glass phase transition model (**Publication #2:** *Study of vortex dynamics in single crystalline $Ba_{0.54}K_{0.46}Fe_2As_2$ superconductor using dc and ac magnetization, D. Paladhi, C. Zhang, and Guotai Tan, P. Dai and T. K. Nath, Journal of Alloys and Compounds, **686**, 938-945 (2016).).*

Comment#4

(a) **Comment:Abstract. There is a typo in the formula for the root square of M as a function of T.**

Response: We have corrected the typo error in the abstract regarding relation of root square of M as a function of T.

(b) **<u>Comment:</u>Page 10. Vander Waal should read van dear Waals**

Response: In page 10 we have modified 'Vander Waal' by 'Van der Waals'.

(c) **<u>Comment:</u>Fig 1.12. The sample name has to be indicated not only in the text but also in the caption. Correspondence between color and temperature should also be indicated in the caption.**

Response: The sample name has been mentioned now in the figure caption of Fig. 1.12 and correspondence between color and temperature has also been indicated as per suggestion.

(d) **<u>Comment:</u>Page 41. Define the variable r0, where r is Greek rho.**

Response: In page 41, we have defined the variable ρ_0 as $\rho_0 = 2\rho_c U/k_B T$.

(e) **<u>Comment:</u>Page 41. Where Kucera et al. should read whereas Kucera et al.**

Response: In Page 41, 'where Kucera *et al.*' has been modified as 'whereas Kucera *et al.*'

(f) **<u>Comment:</u>Page 47. The statement that U_0 has been determined from the slope of the ln of resistivity plotted against T^{-1}. It should be indicated in which temperature range the slope was used.**

Response: It is clearly explained now in the final version of thesis (Page no 47) regarding the temperature range where slope has been used for finding pinning potential. It is the following.
Temperature range of linear region is very small ($< 0.5\,K$) in zero magnetic field for $x = 0.0$ sample. It depends on applied magnetic field. As magnetic field increases, the temperature range within which curve is linear also increases. We have determined the slope mainly in the temperature range of 30.3-62.5 K for $x = 0.0$ sample in all applied magnetic fields. The temperature range varies for different curves which are corresponds to different magnetic field. We have chosen the region where **Eq. 3.6** ($ln\,\rho\,(T, H) = ln\,\rho_0 - U_0(H)/T + U_0(H)/T_c$) is best linearly fitted.

(g) **<u>Comment:</u>Page 47. The statement that U_0 is 103 meV for the sample without Er doping in zero magnetic field is inconsistent with Eq. 3.5. the equation predicts U_0 to be zero if the magnetic field is zero.**

Response: According to **Thermally Activated Flux Flow (TAFF)** model $\boldsymbol{U = J_c B V_c r_p}$, $\boldsymbol{U = U_0(1 - T/T_c)}$ and $\boldsymbol{\ln\rho\,(T,H) = \ln\rho_0 - U_0(H)/T + U_0(H)/T_c}$. Apparent activation energy $U_0(H)$ could be extracted from the slope of $\ln\rho$ vs 1/T plot. In $Bi_2Sr_2CaCu_2O_8$ system, we have obtained $\boldsymbol{U_0 = 103\ meV}$ at zero magnetic field which seems inconsistent with the above equations. Similar observation has also been reported earlier [Physica B **531**, 58-63 (2018), J. Low Temp. Phys. **174**, 136-147 (2014)] where they have obtained non-zero pinning potential at zero magnetic field in Bi-2201 and Bi-2212 polycrystalline systems. Following are the possible explanation of observing non-zero pinning potential (U_0) at zero magnetic field. High T_c superconductors like $Bi_2Sr_2CaCu_2O_8$ have very low lower critical field (H_{c1}<30 mT), large penetration depth and low coherence length. These types of materials are very sensitive to the exposure of small magnetic field. Temperature dependent resistivity curve shows broadening even at zero magnetic field especially in the region of zero resistive transition. The broadened resistive transition is associated with the onset of superconductivity in individual grains which is strongly influenced by weak externally applied magnetic field. **The broadened resistivity part near zero resistive transition might be influenced by stray magnetic field of the high field measuring instrument**. This weak field broadening is getting reflected when slope is calculated from $\ln\rho$ vs $1/T$ curve and gives non-zero pinning potential at zero magnetic field.

(h) **Comment:Page 47. In the text, Temperature dependent of should read temperature dependence of.**

Response: In text of page 47 'Temperature dependent of' has been now modified as 'Temperature dependence of' in the final version of thesis.

(i) **Comment:Figs. 3.5 to 3.7. In the figure captions, dependent of should read dependence of.**

Response: In the figure captions of Figs. 3.5 to 3.7'dependent of' has been now modified as 'dependence of' in the final version of thesis.

(j) **Comment:Page 63, line 1. Chapter 2 should read Chapter 3?**

Response: Yes, in line 1 of page 63 'Chapter 2' has been modified as 'Chapter 3' in the final version of thesis.