Simulation of Internal Flow Field of Pitot-Tube Jet Pump

Iqra Noor, Ihtzaz Qamar

***Abstract*—**Pitot-tube Jet pump, single-stage pump with low flow rate and high head, consists of a radial impeller that feeds water to rotating cavity. Water then enters stationary pitot-tube collector (diffuser), which discharges to the outside. By means of ANSYS Fluent 15.0, the internal flow characteristics for Pitot-tube Jet pump with standard pitot and curved pitot are studied. Under design condition, realizable k-e turbulence model and SIMPLEC algorithm are used to calculate 3D flow field inside both pumps. The simulation results reveal that energy is imparted to the flow by impeller and inside the rotor, forced vortex type flow is observed. Total pressure decreases inside pitot-tube whereas static pressure increases. Changing pitot-tube from standard to curved shape results in minimum flow circulation inside pitot-tube and leads to a higher pump performance.

***Keywords*—**CFD, flow circulation, high pressure pump, impeller, internal flow, pickup tube pump, rectangle channels, rotating casing, turbulence.

I. Introduction

THE performance of the hydraulic machines, turbines or pumps, is normalized by specific speed. It not only indicates maximum achievable efficiency but also determines the head, power and efficiency curves. Smaller N_s for a constant rotating speed means low flow rate and higher generated pressure head [1].

At very low specific speed, conventional single stage radial pumps suffer disk friction loss and wear ring leakage which results in efficiency drop. Multistage radial pumps can be a solution to this problem but system becomes complex as number of rotating parts increases so does the maintenance cost. Rotary positive displacement pumps are efficient for low specific speeds but noise, vibrations due to pulsating flow and low viscosity limitations are their disadvantages [2]. A low specific speed centrifugal pump finds its applications not only in aerospace industry but petroleum, chemical industry, metallurgy etc. [3].

Simple but robust design of Pitot-tube jet pump or Roto-jet pump makes it favorable compared to conventional pumps for low flow, high head applications. This pump has two key elements: rotating case and stationary pitot-tube type collector. Liquid enters the enclosed vane of rotor, which increases its velocity and static pressure in radial direction, and then the fluid gathers into rotating cavity. From here, it enters the pitot-tube collector where transformation of kinetic energy into potential energy takes place [4]. Single stage Pitot-tube Jet (PTJ) pump can achieve 1.6 times the pressure head compared to conventional designs for a given geometry and rotational speed of pump [5].

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Several authors have investigated pump performances and internal flow conditions in rotating case. Komaki et al. experimentally presents the pump performance to get higher head with higher discharge with the higher efficiency [6], 3D numerical simulation for internal flow of impellers of pitot-tube pump [7].

Impellers with rectangular channel, compound impellers and backward inclined impellers are designed by Yang Jun-hu et al., with conclusion that impellers with rectangular channel are better as compared to other two impellers [8]. Si et al. conclude by combination of simulation and experiment that rectangular channel impellers should be preferred for Roto-jet pump of small flow rate. Zang et al. study the impacts of spread angle of rectangular channel impellers on internal flow fields in pump and concluded that the rectangle channel impeller with 6^{o} spread angle is a better type for pitot-tube jet pump. Other impellers with different spread angle have unstable velocity distribution, backflow and big whirlpool [9].

The effect of pitot-tube shape on performance is investigated using optimization with design of experiments (DOE) by Meyer et al. [2]. They presented two CFD approaches: low-fidelity method (limited accuracy but computationally efficient) and high-fidelity approach (computationally expensive and detailed). They conclude that higher performance can be achieved by pitot-tube optimization [2]. Komaki et al. present the relation between pump performance and flow conditions both experimentally and numerically. Based upon the results, pitot-tube profile is optimized with the numerical simulation [10]. Diffuser geometry is optimized using 3D, CFD methods by Meyer et al. and advantages and disadvantages are evaluated for diffuser designs w.r.t the reduction of total pressure losses and projected area of diffuser [11].

This paper presents detailed CFD analysis of Pitot-tube Jet pump with straight pitot and curved pitot which reveals flow field inside the pump and also effect of pitot-tube profile on pump performance is discussed.

II. Pump Design Parameters

Design parameters of a single stage, low specific speed, pitot-tube jet pump are shown in Table I.

A. Pump Geometry

Based on above mentioned parameters, pump is designed and 3D model is created using SOLIDWORKS.

TABLE I
DESIGN PARAMETERS

Medium	Water
Rotational speed	3500 rpm
Flow rate	1 kg/s
Head	102 m
Specific speed	0.0651

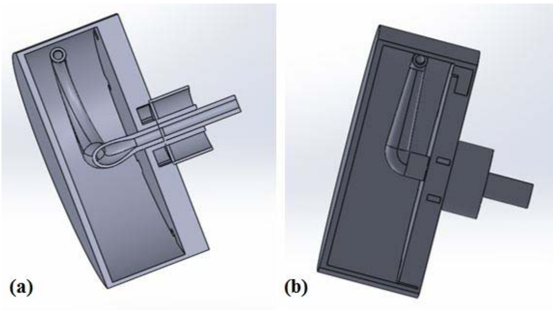

Fig. 1 Pitot-tube Jet Pump with curved pitot-tube (a) and Pitot-tube Jet Pump with conventional pitot-tube (b)

Closed impeller with rectangular channels is designed based on conclusions drawn by Zang et al. [9] and is attached to the rotor.

TABLE II
IMPELLER BLADE PARAMETERS

Total number of blades	8
Blade spread angle	39 degree
Flow channel spread angle	6 degree

Two different diffuser geometries are designed for the present study; Straight (conventional) pitot-tube and curved pitot-tube as shown in Fig. 1, keeping all other dimensions same.

III. NUMERICAL CALCULATIONS

A. Computational Methods

Selected mesh for both pumps has 857620 elements for rotor, 65793 for pitot and 6966 for inlet.

ANSYS Fluent 15.0 is used to solve the governing equations with Finite-Volume approach. All calculations are 3D and steady state, using pressure-based solver.

TABLE III
FLUENT SOLVER SETTINGS

Pressure-velocity coupling scheme	SIMPLEC
Turbulence model	Realizable k-e
Spatial discretization	
Gradient	Least square cell based
Pressure	2^{nd} order upwind
Momentum	2^{nd} order upwind
Turbulence K.E and dissipation rate	2^{nd} order upwind
Number of Iterations	1000
Residuals	$< 10^{-6}$

B. Boundary Conditions

TABLE IV
BOUNDARY CONDITIONS

Inlet	Mass flow inlet
Outlet	Pressure outlet
Wall – No slip boundary condition	
Inlet	Stationary
Outlet	Stationary
Rotor	Rotating – 3500 rpm
Interface	Frozen rotor

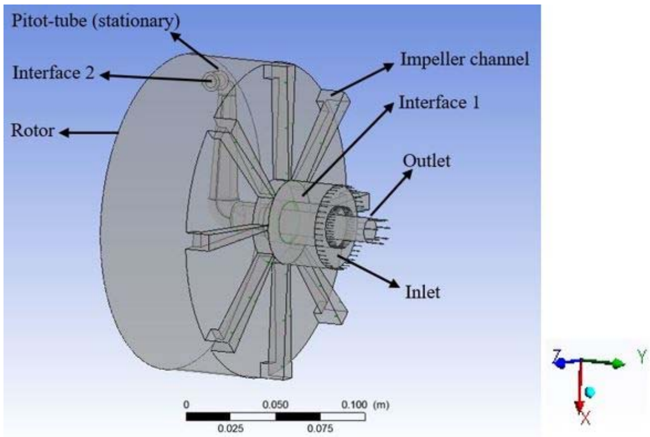

Fig. 2 Computational Domain

IV. FLOW ANALYSIS

A. Conventional Pitot-Tube Jet Pump

Purpose of impeller is not only to increase fluid's velocity and pressure but it also to direct the fluid towards rotor.

Pressure and velocity counters in Figs. 3 and 4 show that fluid is accelerating and both total and static pressure of water increases inside impeller. At the blade end, velocity is even higher, as shown in Fig. 4, indicating high speed and greater dynamic pressure.

Energy is imparted in fluid by impeller. Rotor cavity rotation cannot do work for the fluid [12]. Static pressure, shown in Fig. 5, inside rotor cavity follows a forced vortex pressure distribution given by formula [13]

$$P(r) = P_{suction} + \frac{\rho r^2 \omega^2}{2g} \quad (1)$$

From Fig. 5, it is clear that total and static pressure increases as radius increases. Value of the total pressure is maximum at pitot (diffuser) inlet as shown in Fig. 6. Velocity varies inside rotor according to v = r ω.

B. Pitot-Tube Jet Pump with Curved Pitot

Only diffuser geometry is changed for the analysis of this pump. Dimensions and other parameters are same. Similar trend was observed for pressure and velocity variation in impeller, rotor and diffuser.

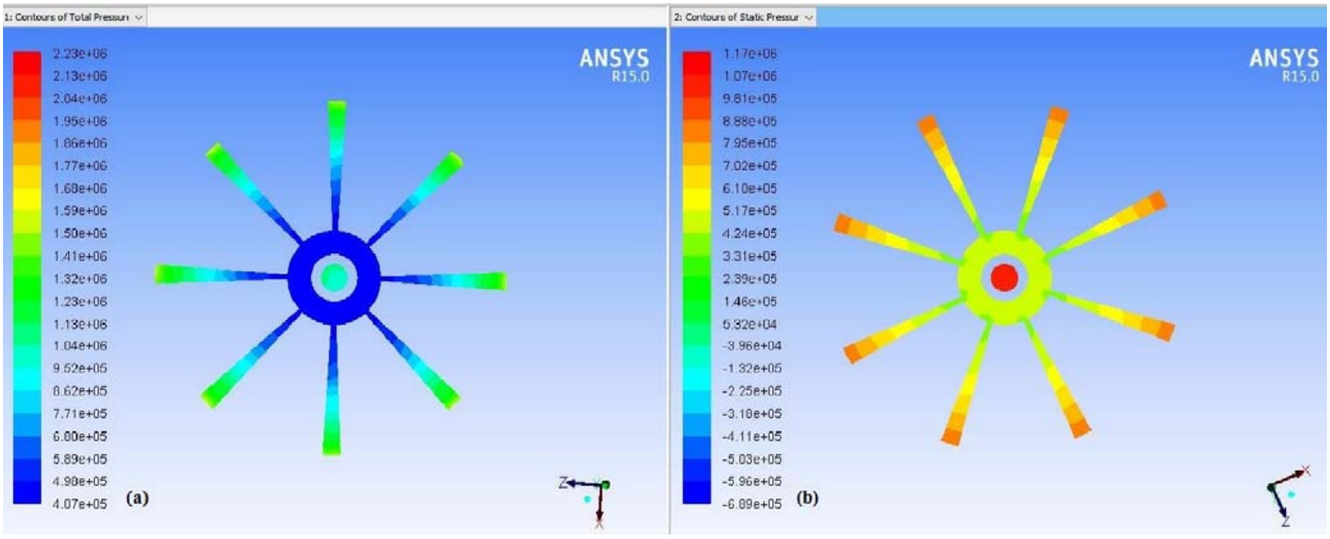

Fig. 3 Total pressure contours (a) and static pressure contours (b)

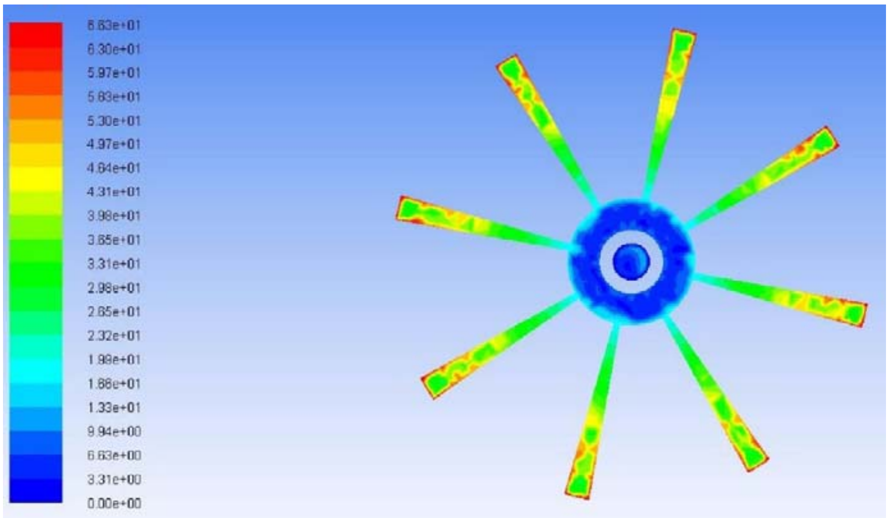

Fig. 4 Velocity contours inside impeller

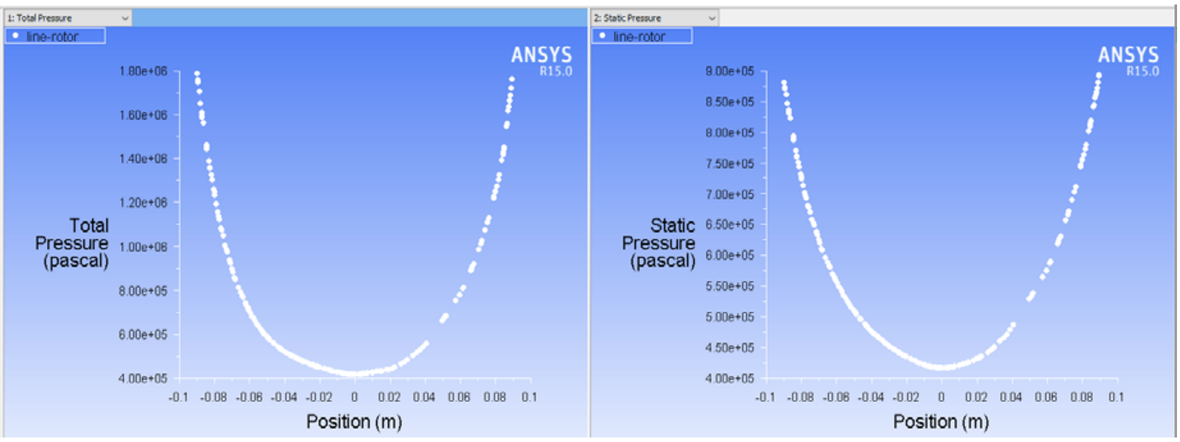

Fig. 5 Pressure distribution inside rotating cavity

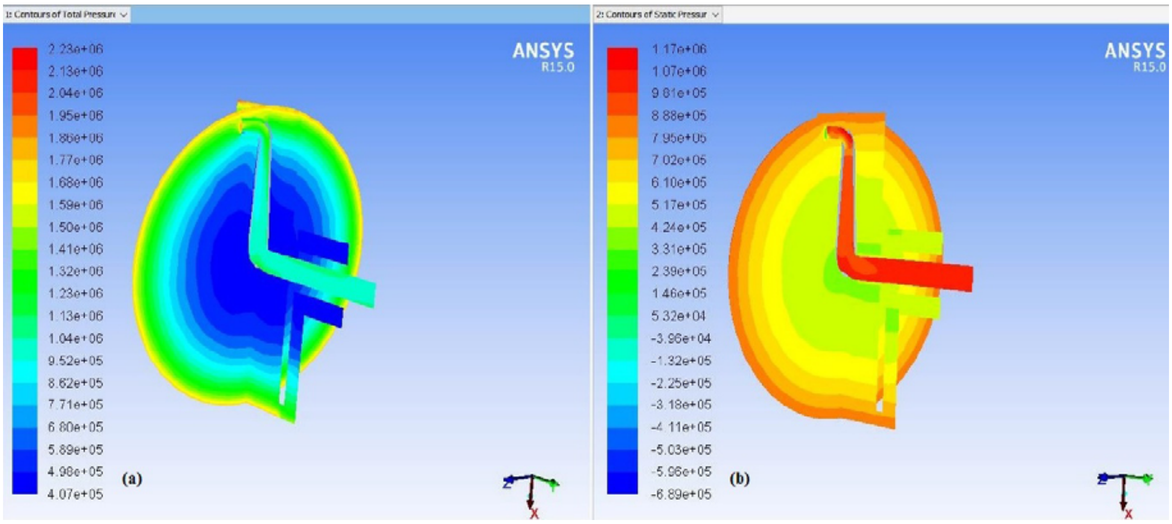

Fig. 6 Pressure contours inside rotor and diffuser

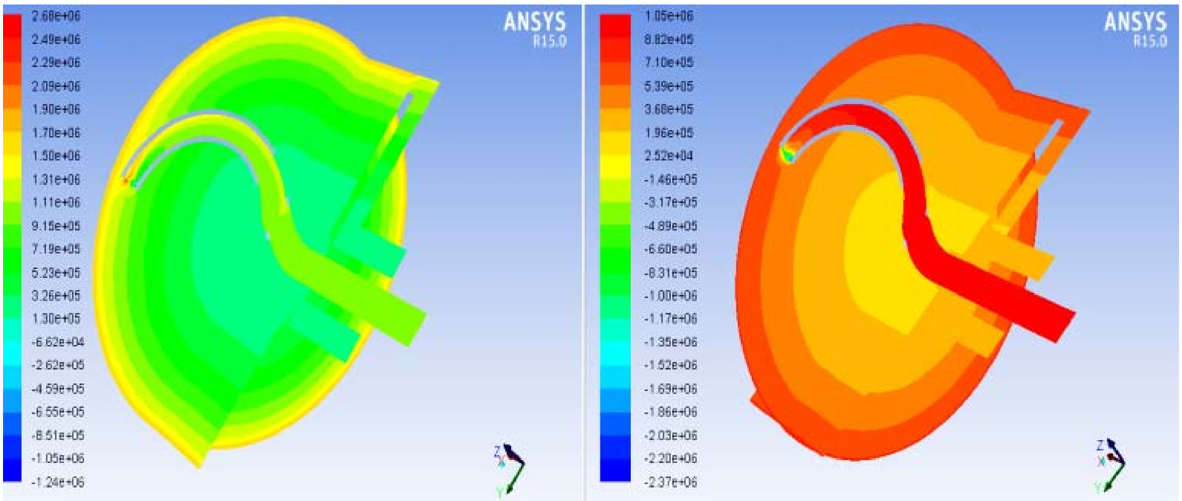

Fig. 7 Contours of total pressure and static pressure inside rotor and pitot-type diffuser

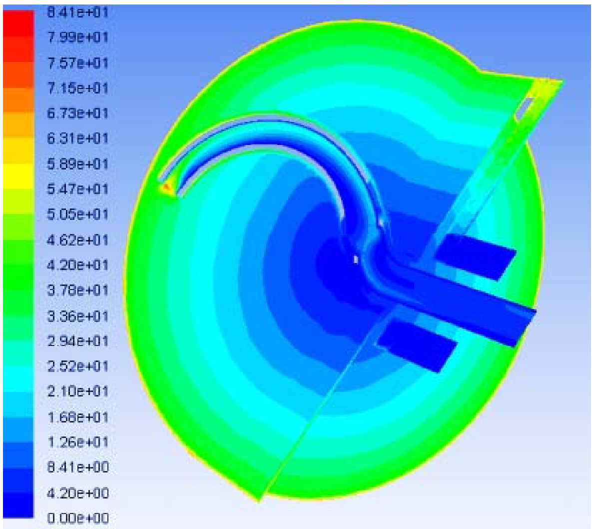

Fig. 8 Velocity contours

C. Comparison

To generate 102 m head, PTJ pump with straight pitot-tube require 4.5 bar pressure at the inlet whereas curved pitot-tube jet pump requires 2.5 bar inlet pressure.

In Figs. 9 and 10, vectors and streamlines show circulation and backflow inside the conventional pitot which results in losses. In case of curved pitot-tube jet pump, gradual variation in curvature decreases circulation inside diffuser.

V. Conclusion

Impeller not only passes fluid from inlet to rotating cavity but also increases velocity and pressure of fluid. Rotation of rotor cannot provide a lot of pressure to fluid. Inside the rotor, minimum pressure exists at the center and as radius increases, pressure and velocity increases. At the inlet of pitot-tube, pressure is maximum.

Pitot-tube profile plays an important role in performance of pump. Gradual change in curvature of the pitot-tube results in minimum circulation and higher pump performance.

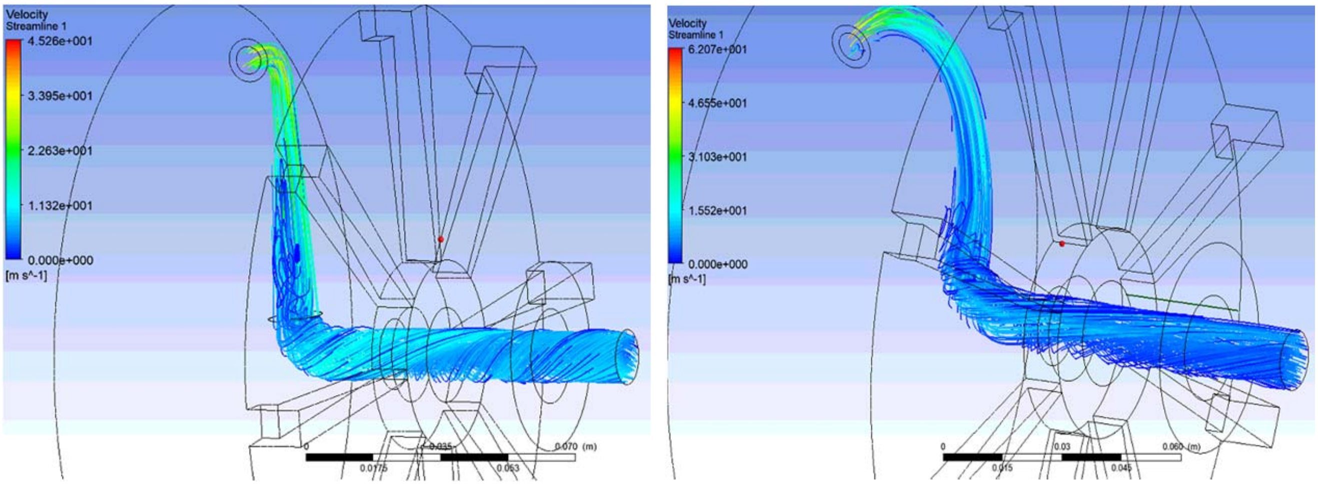

Fig. 9 Velocity vectors inside curved and conventional (straight) pitot-tube

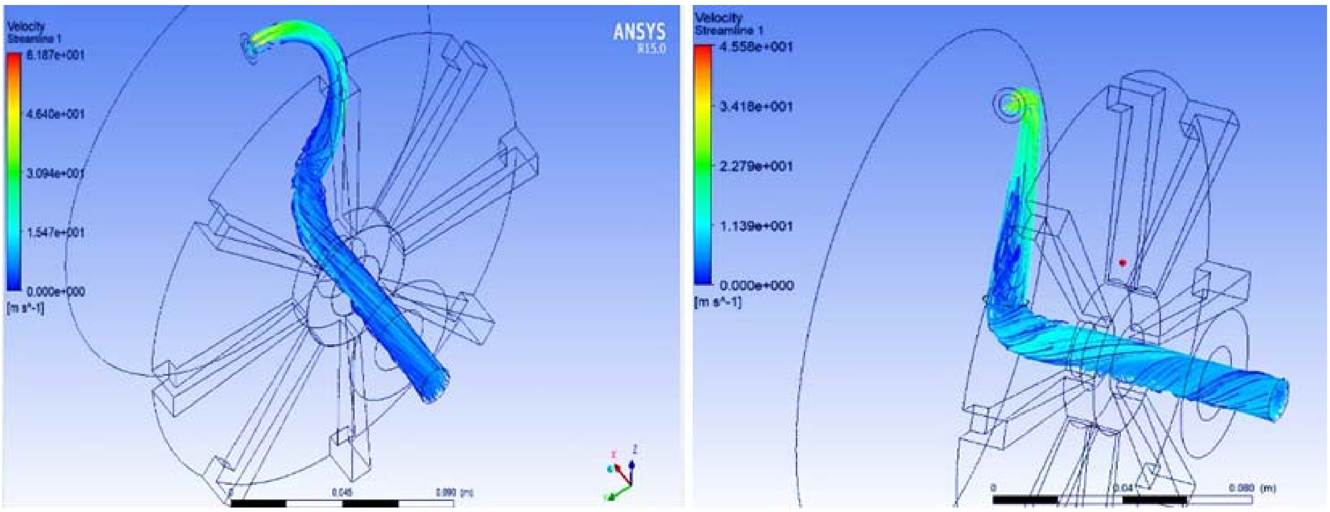

Fig. 10 Streamlines showing circulation inside pitot-tube

ACKNOWLEDGMENT

The author would like to express sincere gratitude to Dr. Ihtzaz Qamar for his patience, professional assistance and insightful suggestions.

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