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Edited by:
D. T. Spasic
N. Grahovac
M. Zigic
M. Rapaic
T. M. Atanackovic

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http://icfda16.com/public/

2014 ICFDA'14 International Conference on Fractional Differentiation and its Applications, Catania, Italy
http://www.icfda14.dieei.unict.it/

2013 FDA'13 The Sixth IFAC Workshop on Fractional Differentiation and Its Applications, Grenoble, France
http://www.gipsa-lab.fr/SSSC2013/

2012 FDA'12 The Fifth Symposium on Fractional Differentiation and its Applications, Nanjing, China
http://em.hhu.edu.cn/fda12/

2010 FDA'10 The Fourth IFAC Workshop on Fractional Differentiation and its Applications, Badajoz, Spain
http://web.tuke.sk/fda10/

2008 FDA'08 The Third IFAC Workshop on Fractional Differentiation and its Applications, Ankara, Turkey
http://fda08.cankaya.edu.tr/

2006 FDA'06 The Second IFAC Workshop on Fractional Differentiation and its Applications, Porto, Portugal
http://www.gecad.isep.ipp.pt/FDA06/

2004 FDA'04 The First IFAC Workshop on Fractional Differentiation and its Applications, Bordeaux, France
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Foreword

The present volume contains plenary lectures, extended abstracts, papers and posters to be presented at the International Conference on Fractional Differentiation and its Applications. The objective of this conference, to be held at Novi Sad during the period 18th - 20th July 2016, are to review and discuss some of the latest trends in various fields of theoretical and applied fractional calculus. By presenting the original high level work and bringing together the experts and young researchers, it aims to promote exchange of ideas in topics of mutual interests, to establish links between scientific communities with complementary activities and to encourage them for collaboration in times to come.

The number of accepted papers to be presented in this 8th FDA event is Congress is 110. These papers were grouped in the following sections: Applications of FC, Biomechanics, Control, Engineering, General Problems of FC, Mathematics, Numerical Methods. Moreover, the Mini-symposia on Recent trends in numerical methods for fractional PDEs was organized. In addition, among them, 11 invited plenary lectures are planed to be presented by the authors from Belgium, Bulgaria, China, France, Germany, Italy, Russia, Serbia, Turkey and UAE. All these contributions were recorded on the attached electronic storage device.

The Editors would like to express their thanks to all participants. First, to the authors of the papers whose quality work is the essence of this event. Next, to the distinguished invited lecturers who kindly accepted the invitation to come to ICFDA16 and helped make it success. Special thanks are to the reviewers of the papers, to the members of the International Program Committee, the Organizing Committee and to the organizers of the Mini-symposia. The support of international organizations: IFAC (International Federation of Automatic Control), IUTAM (International Union of Theoretical and Applied Mechanics), IEEE Branch of Serbia and Montenegro (Institute of Electrical and Electronics Engineers) in organizing this event is appreciated. Special thanks are also due to those organizations which supported financially this event: University of Novi Sad, Faculty of Technical Scineces, Department of Mechanics, as well as Serbian Society of Mechanics, Serbian Academy of Sciences and Arts Branch in Novi Sad and Ministry of Education, Science and Technological Development of the Republic of Serbia. Finally, technical support of the Panacomp agency in preparing and making this event was precious.

It is our pleasure to welcome you to the International Conference on Fractional Differentiation and its Applications. The Organizing Committee has done its best to make this event with an atmosphere favorable for you to participate and increase your professional links.

Novi Sad, July 2016

The Editors
Dragan T. Spasic
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Series in 3-parameter Mittag-Leffler functions – various convergence theorems

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Abstract

The special function $E^{\gamma}_{\alpha,\,\beta}$, defined in the whole complex plane $\mathbb{C}$ by the power series

$$E^{\gamma}_{\alpha,\,\beta}(z)=\sum_{k=0}^{\infty}\frac{(\gamma)_k}{\Gamma(\alpha k+\beta)}\frac{z^k}{k!},\qquad \alpha,\ \beta,\ \gamma\in\mathbb{C},\quad Re(\alpha)>0, \tag{1}$$

where $(\gamma)_k$ is the Pochhammer symbol $(\gamma)_0=1$, $(\gamma)_k=\gamma(\gamma+1)\dots(\gamma+k-1)$, arises as a natural generalization of the Mittag-Leffler functions E_α and $E_{\alpha,\beta}$. It was introduced by Prabhakar in 1971 in his paper [16]. Plenty of various properties of this function are studied by many authors, among them [4, 5, 6, 7, 15], and many others. Actually, the special role of the Mittag-Leffler type functions in the fractional calculus has been discovered by many scientists from different points of view. For example, they serve as solutions of various engineering and practical problems, i.e. the solutions of some fractional order differential and integral equations can be written in terms of series (or integrals, or series of integrals) of Mittag-Leffler functions and their Prabhakar and multiindex generalizations, see for example in Kiryakova [8], Sandev et al. [20], Herzallah and Baleanu [3]. The functions (1) and series in them have been recently used to express solutions of the generalized Langevin equation, by Sandev, Tomovski and Dubbeldam [20] as well as in the eigenfunction expansion of the solution of two-term time-fractional equations by Bazhlekova and Dimovski [1, 2]. For their recent use in the friction and generalized memory kernels and in the exact solutions of the fractional generalized Langevin equation, see for example Sandev, Metzler and Tomovski [18, 19] as well as Sandev, Chechkin, Kantz and Metzler [17]. Due to this reason, the behaviour of series in families of functions (1) is useful to be studied.

A countable family of functions. In order to obtain the simplest possible results, we specify suitable countable systems of functions, by multiplying the considered functions with appropriate coefficients and power functions. For this purpose, we consider the family of the generalized Mittag-Leffler functions (1) with integer indices of the kind $\beta=n$; $n=0,1,2,\dots$, namely:

$$E^{\gamma}_{\alpha,\,n}(z)=\sum_{k=0}^{\infty}\frac{(\gamma)_k}{\Gamma(\alpha k+n)}\frac{z^k}{k!},\ \ \alpha,\ \gamma\in\mathbb{C},\ Re(\alpha)>0,\ n\in\mathbb{N}_0. \tag{2}$$

Since the generalized Mittag-Leffler functions reduce to two-parametric Mittag-Leffler functions for $\gamma = 1$, all the results connected with the three-parametric generalizations $E^{\gamma}_{\alpha,\,n}$ discussed here, hold true for the corresponding two-parametric Mittag-Leffler functions. More detailed observation shows, as it is given in [12, 14], that some coefficients there can be zero, depending on γ and n, i.e. there exists a number $p \in \mathbb{N}_0$, such that $(\gamma)_k/\Gamma(\alpha k+n) = 0$ for $k = 0, \ldots, p-1$ and $(\gamma)_p/\Gamma(\alpha p+n) \neq 0$. Further, let us specify the families of Mittag-Leffler type functions

$$\left\{\widetilde{E}^{\gamma}_{\alpha,\,n}(z)\right\}_{n=0}^{\infty}; \qquad \alpha,\, \gamma \in \mathbb{C},\ Re(\alpha) > 0, \tag{3}$$

as follows below ($\widetilde{E}^{0}_{\alpha,\,0}(z) = 1$, just for completeness), namely:

$$\widetilde{E}^{0}_{\alpha,\,n}(z) = \Gamma(n) z^n\, E^{0}_{\alpha,\,n}(z),\ n \in \mathbb{N};\ \widetilde{E}^{\gamma}_{\alpha,\,n}(z) = \frac{\Gamma(\alpha p+n)}{(\gamma)_p} z^{n-p}\, E^{\gamma}_{\alpha,\,n}(z),\ \gamma \neq 0,\ n \in \mathbb{N}_0.$$

Series in Mittag-Leffler type functions and their convergence. Let us consider the series in the functions of the families (3), namely:

$$\sum_{n=0}^{\infty} a_n \widetilde{E}^{\gamma}_{\alpha,\,n}(z), \tag{4}$$

with complex coefficients a_n $(n = 0, 1, 2, ...)$. A suitable asymptotic formula, earlier established by the author, allows various results, completely analogical to those for the classical power series, to be proposed. We briefly recall the results given in [13, 14] starting with the domain of convergence of the series (4) – the open disk $D(0; R) = \{z : |z| < R, z \in \mathbb{C}\}$ with a radius of convergence $R = \left(\limsup_{n\to\infty} (\,|a_n|\,)^{1/n}\right)^{-1}$. The series is absolutely convergent in the disk $D(0; R)$ and it is divergent in the domain $|z| > R$. The cases $R = 0$ and $R = \infty$ fall in the general case. Farther, analogously to the classical Abel lemma, if the series (4) converges at the point $z_0 \neq 0$, then it is absolutely convergent in the disk $D(0; |z_0|)$. Moreover, inside the disk $D(0; R)$, i.e. on each closed disk $|z| \leq r < R$, the series is uniformly convergent. Further, let $z_0 \in \mathbb{C}$, $0 < |z_0| = R < \infty$, and g_φ be an arbitrary angular domain with size of $2\varphi < \pi$ and with a vertex at the point $z = z_0$, which is symmetric with respect to the straight line passing through the origin and z_0. Let d_φ be the part of the angular domain g_φ, situated between the angle arms and the arc of the circle centred at the point 0 and touching the arms of the angle. Another interesting result is the Abel type theorem, analogical to the classical Abel theorem for the power series. It refers to the uniform convergence of the series (4) in the set d_φ and the existence of the limit of its sum at the point z_0 from the boundary $C(0; R)$, provided $z \in D(0; R) \cap g_\varphi$, i.e. the limit of the sum of this series, convergent at the point z_0, is equal to the series sum at the point z_0. In general, the inverse proposition is not valid, i.e. the existence of the limit of the series at the point z_0 does not necessarily imply the convergence of the series at this point. However, as it is discussed e.g. in [14], under additional conditions, i.e. if $\lim_{n\to\infty} n a_n = 0$, even more if $a_n = O(1/n)$, such a result holds true.

Boundary behaviour and overconvergence. A result, giving relation between the convergence (divergence) of the series (4) at points on the boundary of its disk of convergence and the regularity (singularity) of its sum at such points is the Fatou type theorem.

Namely, if the series (4) has a radius of convergence $R = 1$, $\lim_{n\to\infty} a_n = 0$, $F(z)$ is the sum of the series (4) in the unit disk $D(0;1)$ and σ is an arbitrary arc of the unit circle $C(0;1)$ with all its points (including the ends) regular to the function F, then the series (4) converges, even uniformly, on the arc σ.

Thus, starting with the domain of convergence and series behaviour near its boundary, passing through the possible uniform convergence on an arbitrary closed arc of the boundary, we come to the natural question: "*What type of conditions should be imposed on the power series that ensure the existence of subsequence $\{s_{p_k}\}$, convergent outside the disk of convergence?*". The answer to this question is given in the early 20th century by Ostrowski [10, 11], see also [9]. Namely, one of his classical results states that a given power series with Hadamard gaps and existing regular points on the boundary of convergence disk is overconvergent, i.e. there exists a subsequence $\{s_{p_k}\}$, convergent outside the disk of convergence. Overconvergence of the series (4) is discussed below. Namely, if the series (4) has a radius of convergence $R = 1$, $F(z)$ is the sum of the series (4) in the unit disk $D(0;1)$, $F(z)$ has at least one regular point, belonging to the circle $C(0;1)$ and $F(z)$ possess Hadamard gaps, then the series (4) is overconvergent.

Conclusion. We emphasize that the results obtained for the series (4) are quite analogous to these for the classical power series $\sum_{n=0}^{\infty} a_n z^n$. As seen, they have the same radius of convergence R, and are both absolutely and uniformly convergent on each closed disk $|z| \leq r < R$. Moreover, if each of them converges at the point z_0 of the boundary $\partial D(0;R)$, then the theorems of Abel type hold for both series in the same angular region. Moreover, if $\lim_{n\to\infty} na_n = 0$, even more if $a_n = O(1/n)$, the inverse proposition is valid. Further, if $R = 1$, $\lim_{n\to\infty} a_n = 0$ and all the points (including the ends) of the arc σ of the unit circle are regular to the sums of both considered series, then the series converge even uniformly, on the arc σ. Finally, under additional conditions both series are even overconvergent.

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