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Summation Formulae Associated with the Extension of Voigt Function and Bessel-Maitland Function and Its Applications

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Abstract

In this paper we establish a series expansion formula which involving Laguerre polynomial and extension of Voigt function in terms of H-function of two variable, by making use of an interesting generating function for Laguerre polynomial. For the sake of illustration, we obtain some special cases of our main results which are interesting and believed to be new.

Keywords

Voigt function, H-function of two variable, Laguerre polynomial, generating function, pseudo-Laguerre polynomial

1. Introduction

The topic of special function is very rich and is constantly increasing with the advent of new problems in the field of application in engineering and applied sciences. In addition, The Voigt functions $K(x,y)$ and $L(x,y)$ were introduced and investigated by Voigt in 1899. For a review of the (unification) generalizations of Voigt functions introduced from time to time. In addition, applications to generalized Voigt function in diverse research areas, such as astrophysical spectroscopy, neutrons physics, statistical communication theory, and plasma physics, the Voigt functions and their various generations have been intensively and extensively investigated by many authors. In this paper, main aim is to construct some expansion formulae connecting with Bessel's Mait-land function, generalized Voigt function and H-function of two variable with the help of generating function of Laguree polynomial and Pseudo-Laguree polynomial. (see also [4,5,6,10,12]).
The generalized Voigt function, Bessel-Maitland function, H-function of two variables
and polynomials that are to be used further are described below:

The generalized Voigt functions investigate and defined by [21] & see also [13]

$$\Omega^{\mu}_{\eta,v,\lambda}[x,y,z] = \sqrt{\frac{x}{2}}\int_0^{\infty} t^n e^{-yt-zt^2} J^{\mu}_{v,\lambda}(xt)dt \tag{1.1}$$

$$(x,y,z,\mu \in R^+; R(\eta+v+2\lambda) > -1),$$

Bessel-Maitland function $J^{\mu}_{v,\lambda}(z)$ is defined by Gupta et.al. [6]:

$$J^{\mu}_{v,\lambda}(z) = \sum_{n=0}^{\infty} \frac{(-1)^n (z/2)^{\upsilon+2\lambda+2n}}{\Gamma(\lambda+n+1)\Gamma(v+\lambda+\mu n+1)} \ (1.2) \qquad (1.2)$$

Srivastava et. al. [19] defined and presents the H-function of two variables in the following contracted notation:

$$H\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} = H[z_1, z_2] =$$

$$= H^{0,n:m_1,n_1;.m_2,n_2}_{p,q:p_1,q_1;.p_2,q_2}\left[\begin{matrix} z_1 \\ z_2 \end{matrix}\middle| \begin{matrix} (a_j;\alpha_j^{(1)},\alpha_j^{(2)})_{1,p} : (c_j^{(1)},\gamma_j^{(1)})_{1,p_1}; (c_j^{(2)},\gamma_j^{(2)})_{1,p_2} \\ (b_j;\beta_j^{(1)},\beta_j^{(2)})_{1,q} : (d_j^{(1)},\delta_j^{(1)})_{1,q_1}; (d_j^{(2)},\delta_j^{(2)})_{1,q_2} \end{matrix}\right]$$

$$= \frac{1}{(2\pi\omega)^2}\int_{L_1}\int_{L_2} \phi(\xi_1,\xi_2)\theta_1(\xi_1)\theta_2(\xi_2) z_1^{\xi_1} z_2^{\xi_2} d\xi_1 d\xi_2 \tag{1.3}$$

where $\omega = \sqrt{-1}$

$$\phi(\xi_1,\xi_2)=\frac{\prod_{j=1}^{n}\Gamma(1-a_j+\alpha_j^{(1)}\xi_1+\alpha_j^{(2)}\xi_2)}{\prod_{j=1}^{q}\Gamma(1-b_j+\beta_j^{(1)}\xi_1+\beta_j^{(2)}\xi_2)\prod_{j=n+1}^{p}\Gamma(a_j-\alpha_j^{(1)}\xi_1-\alpha_j^{(2)}\xi_2)} \quad (1.4)$$

$$\theta_i(\xi_i)=\frac{\prod_{j=1}^{m_i}\Gamma(d_j^{(i)}-\delta_j^{(i)}\xi_i)\prod_{j=1}^{n_i}\Gamma(1-c_j^{(i)}+\gamma_j^{(i)}\xi_i)}{\prod_{j=n_i+1}^{p_i}\Gamma(c_j^{(i)}-\gamma_j^{(i)}\xi_i)\prod_{j=m_i+1}^{q_i}\Gamma(1-d_j^{(i)}+\delta_j^{(i)}\xi_i)}, \text{ (i=1,2)} \quad (1.5)$$

The nature of contours L_1 and L_2 in (1.3), a set of sufficient conditions for the convergence of the integral given by (1.3) and the asymptotic expansion of the H-function of two variables can be found in the book by [17] and see also[1,2,3&20].

Srivastavaet. al. [18] introduced a general class of polynomials represented as:

$$S_V^U[x]=\sum_{r=0}^{[V/U]}(-V)_{Ur}A_{V,r}\frac{x^r}{r!}, \text{ V=0, 1, 2...} \quad (1.6)$$

where U is an arbitrary positive integer and the coefficient $A_{V,r}$ are arbitrary constants, real or complex. We obtained several well-known functions after specializing in the parameter rof $S_V^U[x]$polynomial and in which few are listed below:

We take $U=1, A_{V,r}=\binom{V+\alpha}{V}\frac{1}{(\alpha+1)_r}$in equation (1.6),$S_V^U[x]$reduces to Laguerre

polynomial $L_V^{(\alpha)}[x]$ [15] which were defined as

$$L_V^{(\alpha)}[x]=\frac{(1+\alpha)}{V!}\ {}_1F_1[V;1+\alpha;x] \quad (1.7)$$

Generating function of Laguerre polynomial $L_n^{(\alpha)}[x]$ defined in [15]

$$e^{-t}\sum_{n=0}^{\infty}\frac{L_n^{(\alpha)}(x)t^n}{(1+\alpha)_n}=\ {}_0F_1[-;1+\alpha;-xt] \quad (1.8)$$

Pseudo-Laguerre Polynomialis given by [14]:

$$R_V(\mathrm{a,x})=\frac{(a)_{2V}}{V!\,(a)_{2V}}{}_0F_1[-\mathrm{V};\mathrm{a}+\mathrm{V};x] \quad (1.9)$$

Toscano's Generating function obtained by Shively [16] for Pseudo-Laguerre Polynomial

$$\sum_{n=0}^{\infty}\frac{R_n(a,x)t^n}{((1+a)/2)_n} = e^{2t}{}_0F_1[-;\frac{1+a}{2};t^2-xt] \quad (1.10)$$

2. A Set of Main Results

In this section we establish three series expansion formulae for H-function of two variables including generating function of Lagurее polynomial and pseudo Lagurее polynomial.

Formula 1: Let $q,y,z,\mu\in R^{+}, R(k+\vartheta+2\lambda)>0,\ \alpha>0\ and\ \ a,b>0\ also\ \ then,$

$$\sum_{n=0}^{\infty}\frac{L_n^{(\alpha)}(x)}{2^{2n}(1+\alpha)_n}\Omega^{\mu}_{k+2n-1,\vartheta,\lambda}(q,y,z) =$$

$$\frac{\Gamma(1+\alpha)}{y^{k+\vartheta+2\lambda}}\left(\frac{q}{2}\right)^{\vartheta+2\lambda+1/2} H^{0;1:1;0:1;0}_{1;0:0;2:0;3}\left[\begin{array}{c}\frac{xz}{y^2}\\ \frac{q^2}{4y^2}\end{array}\middle|\begin{array}{c}(k;2,2);\ -\ ;\ -\\ -;(0,1)(-\alpha,1);(0,1)(-\lambda,1)(-\lambda-\vartheta,\mu)\end{array}\right] \quad (2.1)$$

Proof: To prove the Formula (2.1), we take the following generating function for Laguerre polynomial $L_n^{(\alpha)}$ [8,15]

$$e^{-t}\sum_{n=0}^{\infty}\frac{L_n^{(\alpha)}(x)}{(1+\alpha)_n}t^n = {}_0F_1[-;1+\alpha;-xt]\ (2.2) \quad (2.2)$$

Now, we replace t by zt^2 and multiply by $e^{-yt}t^{k-1}J^{\mu}_{\vartheta,\lambda}(qt)$ in the above eq. (2.2) and then integrate both sides with respect to t between the limits 0 and ∞. Next, we express Bessel Mait-land function and ${}_0F_1$ in contour integral form with the help of given [11] in the right hand side, and change the order of summation and integration under the permissible conditions. Then, we arrive at the following integral:

$$\sum_{n=0}^{\infty}\frac{L_n^{(\alpha)}(x)}{2^{2n}(1+\alpha)_n}\int_0^{\infty}e^{-yt-zt^2}t^{k+2n-1}J^{\mu}_{\vartheta,\lambda}(qt)dt = \frac{1}{(2\pi i)^2}\int_{c_1}\int_{c_2}\int_0^{\infty}e^{-yt}t^{k+\vartheta+2\lambda+2\xi_1+2\xi_2-1}\left(\frac{q}{2}\right)^{\vartheta+2\lambda}$$

$$\times\frac{\Gamma(1+\alpha)\Gamma(-\xi_1)\Gamma(-\xi_2)(xz)^{\xi_1}(q/2)^{2\xi_2}}{\Gamma(1+\alpha+\xi_1)\Gamma(1+\lambda+\xi_2)\Gamma(1+\vartheta+\lambda+\mu\xi_2)}d\xi_1 d\xi_2 dt \quad (2.3)$$

Further, we change the order of contour integrals and t-integral under the conditions stated, and evaluate the t-integralin right hand side.Now, reinterpreting the resulting contour integrals in terms of H-function of two variables and expressing the integral involved in the left hand side of the eq. (2.3) in terms of extension of Voigt function (1.1), we get the required result after a little simplification.

Formula 2: Let $q, y, z, \mu \in R^{+}, R(k+\vartheta+2\lambda)>0, \alpha>0$ *and* $a, b>0$ *also then,*

$$\sum_{n=0}^{\infty}\frac{L_n^{(\alpha)}(x)z^n}{2^{2n}(1+\alpha)_n}\Lambda_{k+2n-1,\vartheta,\lambda}^{\mu,a,b}(q,y,z)=\frac{\Gamma(b)\Gamma(1+\alpha)}{\Gamma(b-a)}\left(\frac{q}{2}\right)^{\vartheta+2\lambda+1/2}$$

$$\times H_{1;0:1,2;0,2:0;2}^{0;1:1,1;1,0:0,0}\left[\begin{array}{c|l} -1 & (1+k;1,2,2);(1+b-a,1);-;-;(0,1)(1+b,1); \\ \frac{xz}{y^2} & (0,1),(-\alpha,1);(-\lambda,1),(-\lambda-\vartheta,\mu). \\ \frac{q^2}{4y^2} & \end{array}\right] \tag{2.4}$$

Proof: To demonstrate the Formula 2, we take the following generating function for Laguerre polynomial $L_n^{(\alpha)}$ [8,15].

$$e^{-t}\sum_{n=0}^{\infty}\frac{L_n^{(\alpha)}(x)}{(1+\alpha)_n}t^n = {}_0F_1[-;1+\alpha;-xt](2.5) \tag{2.5}$$

Now, we replace t by zt^2 and multiply by $t^{k-1}\,{}_1F_1(a;b;-yt)\,J_{\vartheta,\lambda}^{\mu}(qt)$ in eq. (2.5) and then integrate both sides with respect to t between the limits 0 and ∞. Next, we express Bessel Mait-land function and ${}_0F_1$ in contour integral form with the help of given [15] in the right hand side, and change the order of summation and integration under the permissible conditions. Then, we arrive at the following integral:

$$\sum_{n=0}^{\infty}\frac{L_n^{(\alpha)}(x)}{2^{2n}(1+\alpha)_n}\int_0^{\infty}e^{-zt^2}t^{k+2n-1}\,{}_1\mathrm{F}_1(\mathrm{a;b;-yt})\,J_{\vartheta,\lambda}^{\mu}(qt)dt = \left(\frac{q}{2}\right)^{\vartheta+2\lambda+1/2}\frac{\Gamma(1+\alpha)\Gamma b}{\Gamma(b-a)}$$

$$\times\frac{1}{(2\pi i)^2}\int_{c_1}\int_{c_2}\int_0^{\infty}e^{-yt}t^{k+\vartheta+2\lambda+\xi_1+2\xi_2+2\xi_3-1}$$

$$\times\frac{\Gamma(b-a+\xi_1)\Gamma(-\xi_1)\Gamma(-\xi_2)(xz)^{\xi_2}(-y)^{\xi_1}(-q/2)^{2\xi_3}}{\Gamma(b+\xi_1)\Gamma(1+\alpha+\xi_2)\Gamma(1+\lambda+\xi_3)\Gamma(1+\vartheta+\lambda+\mu\xi_3)}d\xi_1 d\xi_2 d\xi_3 dt \tag{2.6}$$

Further, we change the order of contour integrals and t-integral under the conditions stated and evaluate the t-integral in right hand side. Now, reinterpreting the resulting contour integrals in terms of H-function of two variables and expressing the integral involved in the left-hand side of the above eq. in terms of extension of Voigt function in second kind, we get the required result after a little simplification.

Formula 3: Let $q, y, z, \mu \in R^{+}, R(k+\vartheta+2\lambda) > 0, \alpha > 0 \; and \;\; a > 0 \; also \;\; then,$

$$\sum_{n=0}^{\infty} \frac{R_n(a,x)}{2^{3n}\left(\frac{1+a}{2}\right)_n} \Omega^{\mu}_{k+2n-1,\vartheta,\lambda}(q,y,z) = \frac{\Gamma(1+\alpha)}{y^{k+\vartheta+2\lambda}} \left(\frac{q}{2}\right)^{\vartheta+2\lambda+1/2}$$

$$\times H^{0;1:1;0:1;0}_{1;0:0;2:0;3}\left[\begin{array}{c} \frac{xz}{y^2} \\ \frac{q^2}{4y^2} \end{array}\middle|\begin{array}{c} (k;2,2); \; - \;\; ; \; - \\ - \;\; ;(0,1)(-\alpha,1);(0,1)(-\lambda,1)(-\lambda-\vartheta,\mu) \end{array}\right] \qquad (2.7)$$

Proof: To prove the Formula 3, we take the following Toscano's generating function in slightly different form in terms of F_1obtainable with the help of [7, 8, 9& see also 11]

$$e^{-2t} \sum_{n=0}^{\infty} \frac{R_n(a,x)t^n}{((1+\mathrm{a})/2)_n} = {}^{0:0:0}_{1:0:0}\left[\begin{array}{c} : - \; ; - \; ; \\ \left(\frac{1+a}{2}\right) \quad : - \; ; - \; t^2, -xt \end{array}\right] \qquad (2.8)$$

in the above equation, we replace t by $zt^2/2$ and multiply by$e^{-yt}t^{k-1}J^{\mu}_{\vartheta,\lambda}(qt)$.Next we integrate both sides with respect to t between the limits 0 and ∞ .Now we express Bessel Mait-land function and $_0F_1$in contour integral form with the help of given [11] in the right hand side, and change the order of summation and integration under the permissibleconditions. Then we arrive at the following integral:

$$\sum_{n=0}^{\infty} \frac{R_n(a,x)z^n}{2^n((1+\mathrm{a})/2)_n} \int_0^{\infty} e^{-yt-zt^2}\, t^{k+2n-1} J^{\mu}_{\nu,\lambda}(qt)\mathrm{dt} = \int_0^{\infty} e^{-yt} t^{k-1} J^{\mu}_{\vartheta,\lambda}(qt)$$

$$\times F^{0:0:0}_{1:0:0}\left[\begin{array}{c} : - \; ; - \; ; \\ \left(\frac{1+a}{2}\right) \quad : - \; ; - \; (\mathrm{z}t^2)^2/4, -xzt^2/2 \end{array}\right] \qquad (2.9)$$

Further, we change the order of contour integrals and t-integral under the conditions stated and evaluate the t-integral in right hand side. Now, reinterpreting the resulting contour integrals in terms of H-function of two variables and expressing the integral involved in the left-hand side of the above equation in terms of extension of Voigt function we easily arrive at formula 3 after a little simplification.

3. Special Cases

In this part we derive several new and known results that can be acquired by giving specific values to the parameters engaged with the main expansion formulas.

(1) In formula 1, we take $\mu = 1, \lambda = 0, z = \frac{1}{4}$, then we get the following result:

$$\sum_{n=0}^{\infty} \frac{L_n^{(\alpha)}(x)}{2^{2n}(1+\alpha)_n} V_{k=2n-1,\vartheta}(q,y) = \frac{\Gamma(1+\alpha)}{y^{k+\vartheta}}\left(\frac{q}{2}\right)^{\vartheta+1/2}$$

$$\times H_{0;1:0;2:0;2}^{0;0:1;0:1;0}\left[\begin{matrix}\frac{x}{4y^2}\\ \frac{q}{4y^2}\end{matrix}\middle|\begin{matrix}(k+\vartheta;2,2); & - & ; & - \\ - & ;(0,1)(-\alpha,1); & (0,1)(-\vartheta,1)\end{matrix}\right] \qquad (3.1)$$

provided that the conditions easily obtainable from the existence conditions (2.1) are satisfied.

(2) In the equation (2.1), setting $x = y^2, z = 1$,then we arrive at the new and interesting result in terms of fox H- function [17] as follows:

$$\sum_{n=0}^{\infty} \frac{L_n^{(\alpha)}(4y^2)(1)^n}{(1+\alpha)_n} \Omega_{k=2n-1,\vartheta,\lambda}^{\mu}(q,1,y) =$$

$$\frac{\Gamma(1+\alpha)}{y^{k+\vartheta+2\lambda}}\left(\frac{q}{2}\right)^{\vartheta+2\lambda+1/2} H_{1;3}^{1;1}\left[\frac{q^2}{4y^2}\middle\|\begin{matrix}\left(\frac{k+\vartheta+2\lambda}{2},1\right)\\ (0,1)(-\lambda,1)(-\vartheta-\lambda,\mu)\end{matrix}\right] \qquad (3.2)$$

provided that the conditions easily obtainable from the existence conditions (2.1) are satisfied.

(3) On taking $\alpha = 0, \lambda = 0, q = 1$ in the eq.(2.1), then we get the interesting result in terms of H-function of two variables as follows:

$$\sum_{n=0}^{\infty} \frac{L_n(x)z^n}{(1+\alpha)_n} \Omega_{k+2n-1,\vartheta}^{\mu}(1,y,z) =$$

$$\frac{1}{y^{k+\vartheta}}\left(\frac{1}{2}\right)^{\vartheta+1/2} H_{1;1:0,2:0,2}^{0;1:1,0:1,0}\left[\begin{matrix}\frac{xz}{y^2}\\ \frac{1}{4y^2}\end{matrix}\middle|\begin{matrix}\left(\frac{k+\vartheta}{2};1,1\right); & - & ; & - \\ - & ;(0,1)(1,1); & (0,1)(1,1)(-\vartheta,\mu)\end{matrix}\right] \qquad (3.3)$$

(4) In the eq. (2.1), on taking $\alpha = 0, \lambda = 0, \mu = 1, \vartheta = 1/2$, then we arrive at the result in terms of H-function of two variables as follows:

$$\sum_{n=0}^{\infty} \frac{L_n(x)z^n}{(1+\alpha)_n} \Omega^1_{k+2n-1,1/2}(x,y,z) = \frac{1}{2y^{k+\vartheta}}$$

$$\times H^{0;1:1,0:1,0}_{1;1:0,2:0,2}\left[\begin{array}{c|c} \frac{xz}{y^2} & \left(\frac{k}{2};1,1\right) \;;\; - \;;\; - \\ \frac{1}{4y^2} & - \;;(0,1)(1,1);(0,1)(1,1)(-1/2,1) \end{array}\right] \tag{3.4}$$

Lastly, if we suitably specialize in the parameters involved in formulas 1, 2 and 3, we can establish the corresponding results. (see [7],[20] & [21])

Conclusion

We recap have givena series expansion formula in terms of H-function of two variables which involving the generating function of Laguerre polynomial and generalized version of Voigt function. Further, we established some interesting new and known results by specializing in the parameters of the main results.

In addition to the identities demonstrated in this section, numerous other formulas can be derived.

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